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ROCKETDYNE

A DIVISION OF NORTH AMERICAN AVIATION, INC.
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HISTORY: PROJECT FIRST, F-1 COMBUSTION STABILITY PROGRAM VOLUME 2, BOOK 3

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FOREWORD

This is Volume 2, Book 3 of the History: Project First, F-1 Combustion Stability Program Report, prepared in compliance with the provisions of contract NASw-16, Mod 36 and Mod 44, attachment B, the Rocketdyne F-1 Engine Development Program for the National Aeronautics and Space Administration.

ABSTRACT

A history of the F-1 Combustion Stability Program from April through June 1964 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described.

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INTRODUCTION

Volume 2, Book 3 reviews the Combustion Stability Program through the months of April, May, and June 1964. It relates program results in the achievement of dynamic stability and injector performance, and attempts to convey the engineering thought that directed the program.

SUMMARY

By the end of June 1964, the basic design features of an FRT injector that would damp instabilities within 100 milliseconds had emerged. Two injector units, which were considered to be FRT candidates, evolved from the F-1 component testing during that quarter. These injectors were tested successfully on an engine.

Analytical studies during this period were directed toward determining the nature of the 500-cps buzz problem. Further study of buzz phenomenon was also undertaken by Rocketdyne's Research Department. Contributions to the analysis effort were also made by the Hydrodynamics Studies Program and H-1 Program.

During this report period, the Spud Test Program was moved to the Neosho, Missouri Facility. Also, an experimental program on the acoustic liner was begun. Other areas of interest at this time included the Bomb Development Program and the Feed System Pulsing Program.

THEORY

During this quarter, Professor Antone Oppenheim of the University of California and the NASA Combustion Stability Ad Hoc Committee consulted with the F-1 Combustion Stability Group. Several concepts and mechanisms of combustion instability were studied and evaluated. The concepts considered included:

1. Mechanism for the reinitiation process for resurge
2. Fuel buffered baffle concept
3. The effect of localized mixture ratios on the total performance and stability of an injector
4. The effect of propellant feed system on the 500-cps buzz-type instability
5. Acoustic liner

MECHANISM FOR THE REINITIATION PROCESS FOR RESURGE

Professor Oppenheim suggested that particular attention be given to the resurge mode of instability and mechanisms of bomb perturbation amplification. In the light of his experiments at the University of Californi Mr. Oppenheim suggested a possible mechanism for the reinitiation process for resurge. In a detonation tube, it has been observed that a secondary explosion takes place in the turbulent burning zone following an accelerating combustion front. This explosion takes place at the wall and, because of the reflections across the tube, a shock is propagated in both directions. One shock system overtakes and modifies the detonation, and the other shock propagates away from the detonation. This secondary

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explosion and subsequent wave system is termed retonation (or redetonation). Professor Oppenheim did not directly associate retonation to resurge, but he postulated that the process by which retonation is believed to be initiated does apply to the resurge mode. The theory of the onset of retonation is that a pocket of unburned species near a wall undergoes implosion, or burning from the outside in. The energy per unit surface area of the burning front increases because the area decreases. Theoretically then, there is infinite pressure at the center. This subsequently produces a high-amplitude "pop." This pop phenomenon was put forward as a possible resurge trigger.

Professor Oppenheim stated true Chapmann-Jouget detonation does not play a role in the resurge instability. The disturbances are of other explosive nature. It was suggested that the high-amplitude waves observed could be explained by coalesced pressure waves generated by the accelerating burning process.

FUEL BUFFERED BAFFLE CONCEPT

The observed destabilizing effects of propellant spray mismatching adjacent to the thrust chamber wall has led to the fuel buffer concept. Mismatching of oxidizer and fuel sprays adjacent to confining surfaces is believed to cause a degradation of stability for the following reasons:

1. For a given change in combustion rate near a confining surface, the amplitude of the change in localized gas velocity will be approximately twice as great as for the case where the localized change in combustion rate occurs at a remote position with respect to the confining surface. Thus, joint impingement of oxidizer and fuel on a confining surface (baffle or thrust chamber wall) should be detrimental for stability.

2. The sustaining energy for unstable combustion is increased because a deflection of the interlapped propellant sprays adjacent to the confining surface produces a greater change in mixing rate than for the case where only one propellant is injected adjacent to the confining surface.

3. The bulk density of the propellant sprays and gases next to the confining surface is increased when misalignment occurs. This is because the oxidizer sprays, in addition to the fuel sprays, impinge on the confining surface. Since the bulk density is greater, the ease with which high over-pressures can be generated is enhanced. That is, the greater density tends to increase the degree of confinement because of the higher inertial resistance to velocity changes. In turn, the higher concentration of propellant causes a greater combustion rate change for a given velocity change. These conditions are conducive toward the generation of large localized changes in combustion rate or over-pressures.

The fuel buffer concept was evolved to rectify the adverse effects of propellant spray mismatching adjacent to confining surfaces. This consists of blanking off the existing fuel pairs adjacent to the radial baffles and redrilling holes which impinge across oxidizer rings. This arrangement allows fuel fans to be matched with the oxidizer fans in a manner similar to that which exists adjacent to the thrust chamber wall. The oxidizer orifices adjacent to the circumferential baffles are blanked off, allowing fuel only to strike the circumferential baffles. This improves stability by preventing high-density oxidizer and fuel from striking jointly on the baffle surfaces and also prevents high-density oxidizer streams from extending excessively far downstream adjacent to the confining surface. The provision of fuel fans matched radially with adjacent LOX fans along the circumferential baffles also provides the same effect.

It should be noted that the provision of circumferential fuel fans adjacent to the radial baffles does not result in off-mixture-ratio conditions in the region of the baffles. The fuel orifices matched with the oxidizer orifices adjacent to the baffles are reduced in size to compensate for the fuel which is passed through the fuel holes which form the circumferential fuel fans.

THE EFFECT OF LOCALIZED MIXTURE RATIOS ON THE TOTAL PERFORMANCE AND STABILITY OF AN INJECTOR

Figure 1 illustrates the mixture ratio profile vs radial distance along the injector face for a typical injector. It is considered possible that to improve the performance of an injector, the local mixture ratio in the outer periphery and along the baffles must be brought closer to the rated value. To improve the mixture ratio around the baffles, dump coolant may be increased or the oxidizer orifices adjacent to the baffles may be reduced in size. A reduction in fuel flow in the outer ring would increase the mixture ratio in the outer periphery to the rated value. Also, by restricting the fuel flow in the outer ring the injection density in the outer periphery is lowered. Since the injection density in the outer periphery is lower than in the center, dissipation or venting of an over pressure into an area of lower propellant concentration can be accomplished. Theoretically, by reducing the fuel flow through the outer ring, injector performance and stability should improve.

THE EFFECT OF PROPELLANT FEED SYSTEM ON THE 500-CPS BUZZ-TYPE INSTABILITY

The effects of the propellant feed system on the 500-cps buzz-type instability have not been clearly determined. Parameters such as feed system and injection pressure drops have been found to be significant. However,

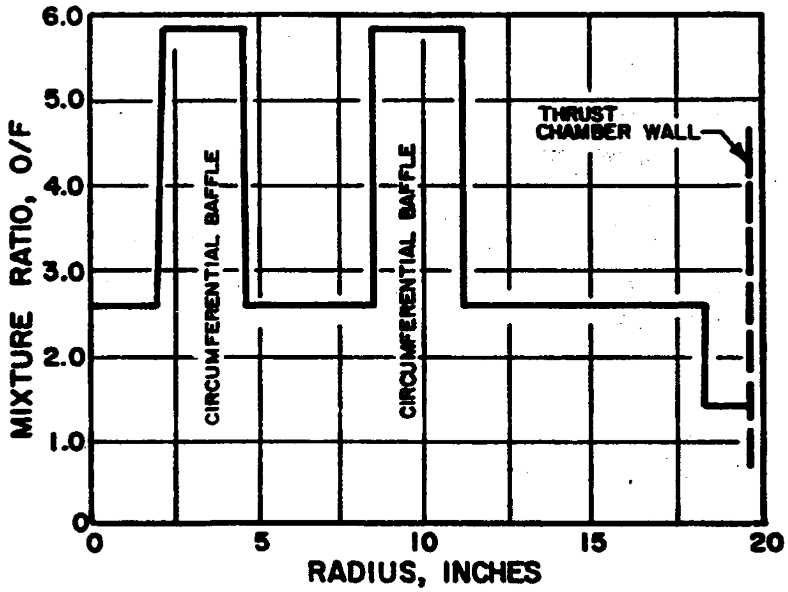

Figure 1. **Mixture Ratio vs Radial Distance From Center of Injector**

it has been postulated that feed system geometry may play an important role in the 500-cps buzz problem. Out-of-phase conditions have been known to exist across both the LOX dome and fuel manifold. Usually nodal lines can be drawn connecting the inlets on both LOX dome and fuel manifold. This out-of-phase condition is believed to cause oscillations in the LOX axial feed holes and in the ring grooves of the injector. Similarly, the out-of-phase condition existing in the fuel manifold is believed to induce an annular mode in the fuel ring grooves and circumferential baffles. Also, because of its geometry, the fuel manifold may be resonating at 500 cps and transmitting the oscillations directly to the combustion chamber. Figure 2 is an example of the 500-cps buzz-type instability. The traces appear sinusoidal, and the amplitude remains relatively constant. The fuel, LOX, and chamber pressure oscillations indicate a feed-system-coupled mode.

ACOUSTIC LINER

During this report period, the application of an acoustic liner as a possible combustion instability suppressing device was investigated. The acoustic liner consists of an array of Helmholtz resonators. A plane wave impinging on it is partially absorbed and partially reflected. Maximum absorption occurs when the incident wave is of the same frequency as the resonant frequency of the liner cavities. The amount of absorption and band width of the absorption curve can be adjusted by varying the geometry of the resonator cavities and fraction of open area of the liner surface.

The acoustic liner program is discussed in detail in the section entitled Experimental Programs.

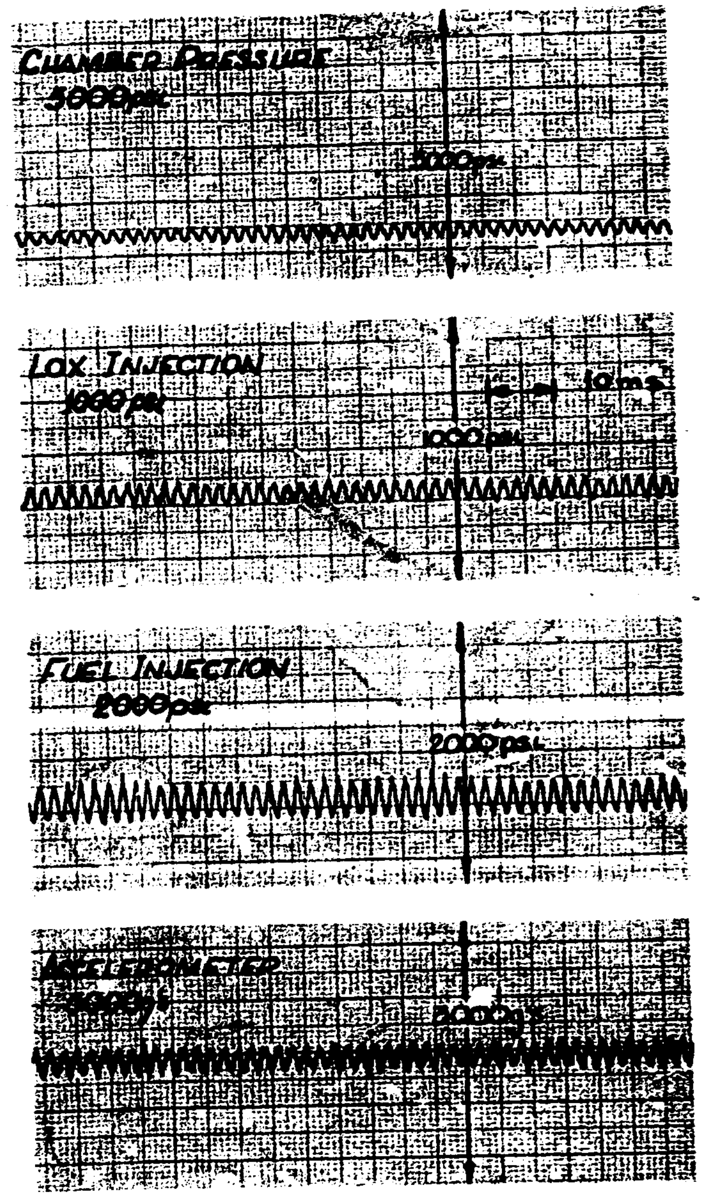

Figure 2. Example of the 500-cps Buzz Type Instability

ANALYSIS

The analysis for this period was composed of five separate areas of study as follows:

1. F-1 engine analysis
2. Test stand 2A component analysis
3. H-1 for F-1 program
4. Test stand 2A calibration
5. Hydrodynamics

F-1 ENGINE ANALYSIS

During this period, 35 series of tests on 13 different injector units were conducted on the component test stand. In addition, 24 engine tests on the 5U baffled injectors were conducted.

Engine testing consisted primarily of continued evaluation of the 5U baffled injector. During the quarter, 24 tests were conducted on four 5U baffled injector units of the type shown in Fig. 3. Also, 10 tests were conducted on two new injector units of the type shown in Fig. 4. The injectors, illustrated by Fig. 4, were considered to be FRT candidates.

Seven tests were conducted with injector unit 092 to investigate the performance and burning characteristics of this injector in an engine. The average estimated specific impulse for these tests was 262.0 seconds. Chamber tube erosions and cracks were noticed during the testing.

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Figure 3. Injector Unit F1002, Type 5828V

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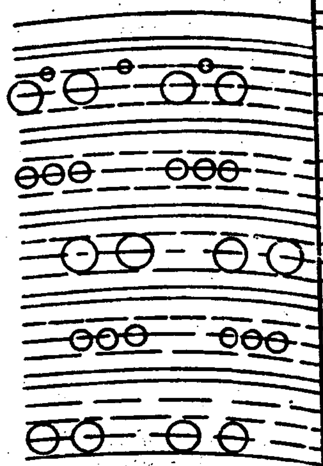
INJECTOR DESCRIPTION

UNIT F1002, TYPE 5828V, S/N ______

ORIFICE PATTERN

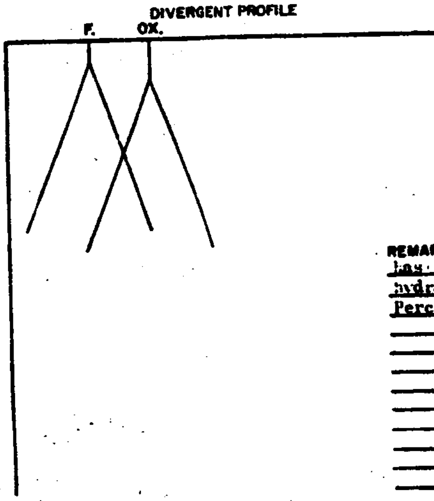


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	34.188							
	37.961	0.1285	184/200	—				
	37.776	0.228	96/104	0.416	20	1.14	0.571	0.258
	36.746	0.185	96/104	0.416	20	1.11	0.571	0.317
	35.626	0.228	88/96	0.416	20	1.17	0.571	0.258
	34.506	0.185	88/96	0.416	20	1.13	0.571	0.317
	33.386	0.228	80/88	0.416	20	1.17	0.571	0.258

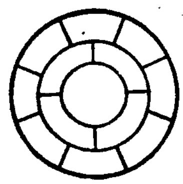
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	62.3	53.3
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.916	
Inj Velocity (1500 F)	75.7	153.5

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Body coolant 0.076-inch diameter; has SME orifices except in outer ring; hydraulic modification II; Percent film coolant = 10.8

Figure 3. (Concluded)

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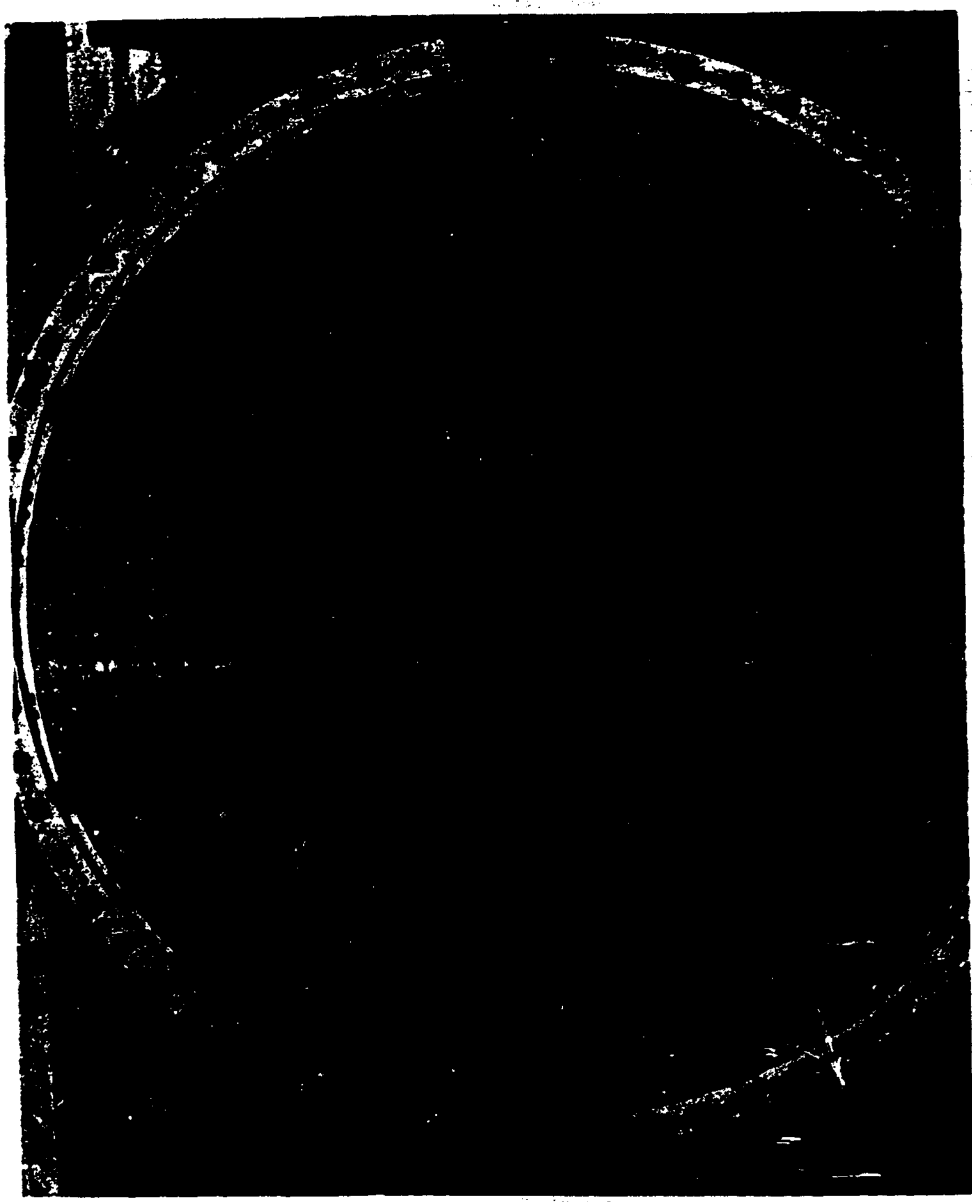

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Figure 4. Injector Unit 092, Type 5867J3

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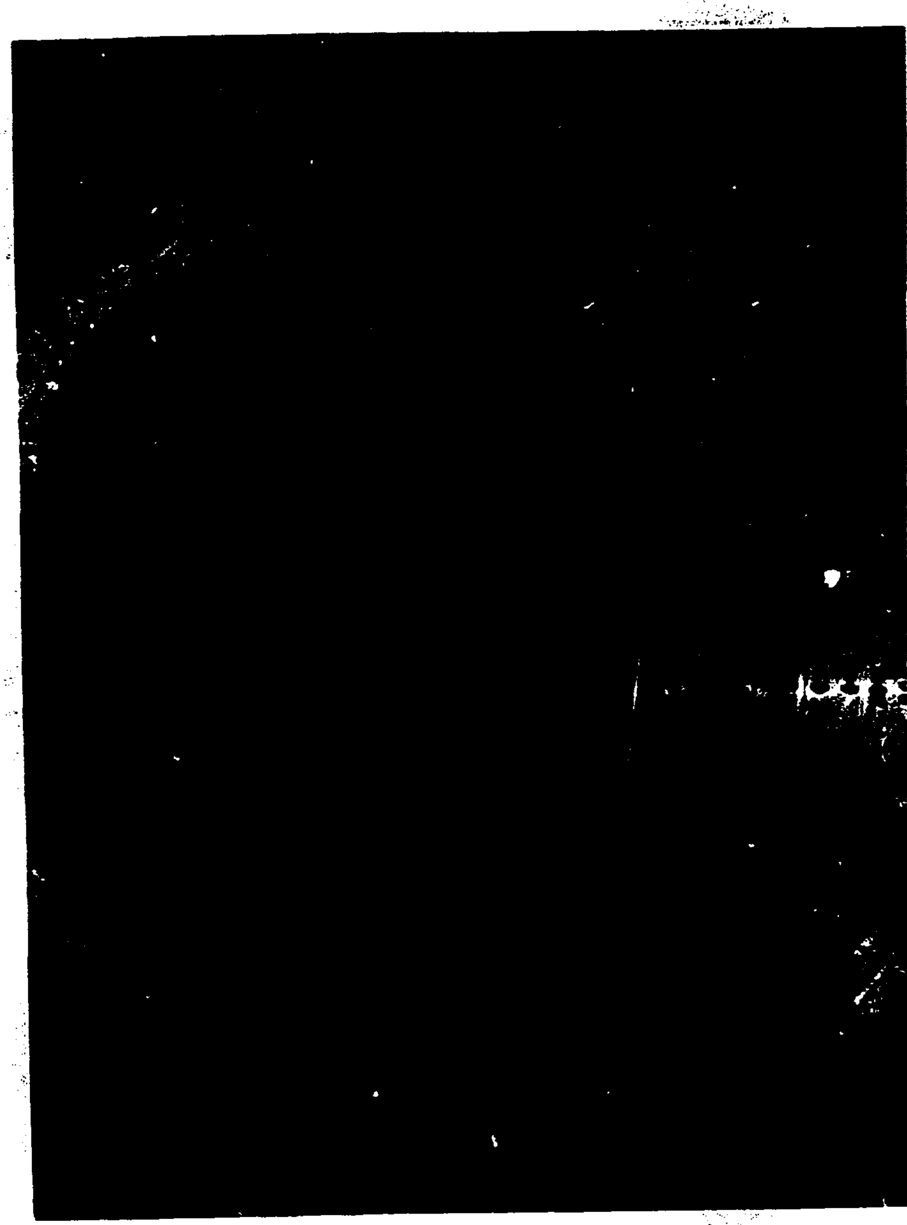

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Figure 4. (Continued)

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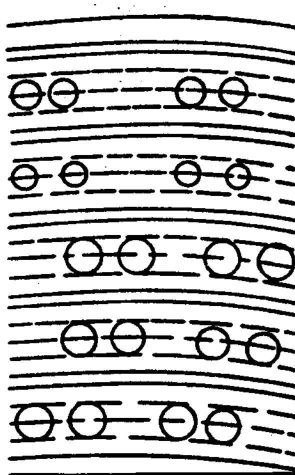
INJECTOR DESCRIPTION

UNIT 092, TYPE 586733, S/N

ORIFICE PATTERN

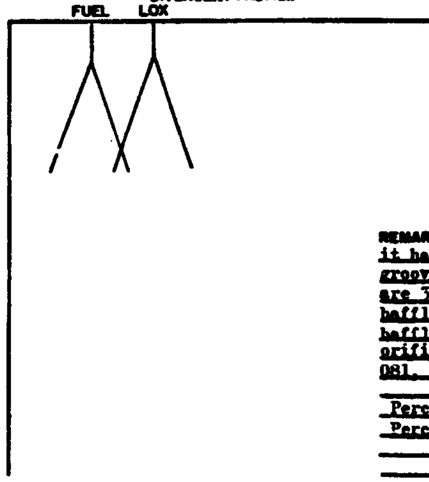


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjl
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
-55	35.626	0.281	88/96	0.428	15°	1.17	0.744	0.254
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.238
Except LOX holes (0.209) next to all baffles								
-51	33.386	0.281	80/88	0.428	15°	1.22	0.744	0.254

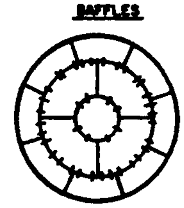
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Velocity ([illegible])	55.6	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is like unit 081 except it has rotated baffles, baffle dams, deep LOX grooves and fuel port isolation tabs. There are 32 baffle dams in the outer circumferential baffle and 8 dams in the inner circumferential baffle. 314 LOX splitters. Outer ring is orificed for 30% flow. Splitters placed as in 081, 5867 A3.

Percent film coolant = 2.3

Percent excess fuel on wall = 1.1

Figure 4. (Concluded)

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Injector unit X056, which was built to the same specifications as injector unit 092, was fired three times. Engine specific impulse ranged from 259.9 to 260.5. On the last test, a 13.5-grain bomb induced an instability which persisted for 390 milliseconds. A rough combustion cutoff (RCC) was incurred after 1.6 seconds of mainstage operation. The mode of instability was identified as resurging coupled with 500-cps out-of-phase oscillations across the oxidizer dome. Posttest inspection revealed two split tubes and 68 collapsed tubes near the injector face. The outer radial baffles were bent in a clockwise direction. A summary of the engine tests on the FRT candidate injectors is presented in Table 1.

TEST STAND 2A COMPONENT ANALYSIS

Testing on the 2A component stand consisted of continued evaluation and study of the problems concerning stability and performance. During this period, an FRT candidate injector evolved from the component stand testing. This injector type was mentioned previously and is shown in Fig. 4.

The following concepts were tested and evaluated. (A discussion of these concepts follows later in the text):

1. The effect of complete isolation of the oxidizer dome on the 500-cps buzz
2. The effect on resurging of enlarging the oxidizer orifices along the radial baffles
3. The effect of reducing the size of the oxidizer orifices on the 500-cps buzz
4. The effect of plugged outer rings or wall gap on dynamic stability

[redacted]

TABLE 1

F-1 ENGINE TESTING EFFORT

Test: 029 through 035 (1B-1) engine 020, 5-28-64 to 6-19-64

Injector Type: 5867J3, U/N: 092, Aot: 58.8, Aft: 85.1, Vo(1500K): 138.9, Vf(1500K): 55.6

Description: 5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diamater at 40 degrees and is orificed to half flow in axial feed holes); 0.242-inch diameter LOX doublets at 40 degrees (outer LOX ring is 0.209-inch diameter at 40 degrees, LOX holes next to baffles are 0.209-inch diameter at 40 degrees); 314 LOX splitters; 32 dams in the outer circumferential baffle and 8 dams in the inner circumferential baffle, no film or body coolant holes, 2.3 percent film coolant

Objective: Investigation of performance and burning characteristics of this injector in the engine

Test Results: Thrust was not measured for the first five tests. Performance was calculated based on estimated thrust derived from P_c. Test durations were 10, 50, 90, 150, and 105 seconds, respectively. The average estimated I_s for those tests was 262.0 seconds. The seventh test was 24 seconds in duration and had an I_s = 261.5 seconds with measured thrust. The last test was cut off by a chart observer after only 3 seconds of mainstage duration. Throughout the test series the thrust chamber developed 15 transverse tube cracks (mostly in tooling marks) in the convergent section, two tube erosions, and a local erosion to the exit manifold. All cracks were in down tubes. Other down tubes evidenced thermal rippling. The nozzle extension was installed for the 24- and 3-second tests. No damage other than overheating was noted.

TABLE 1

(Concluded)

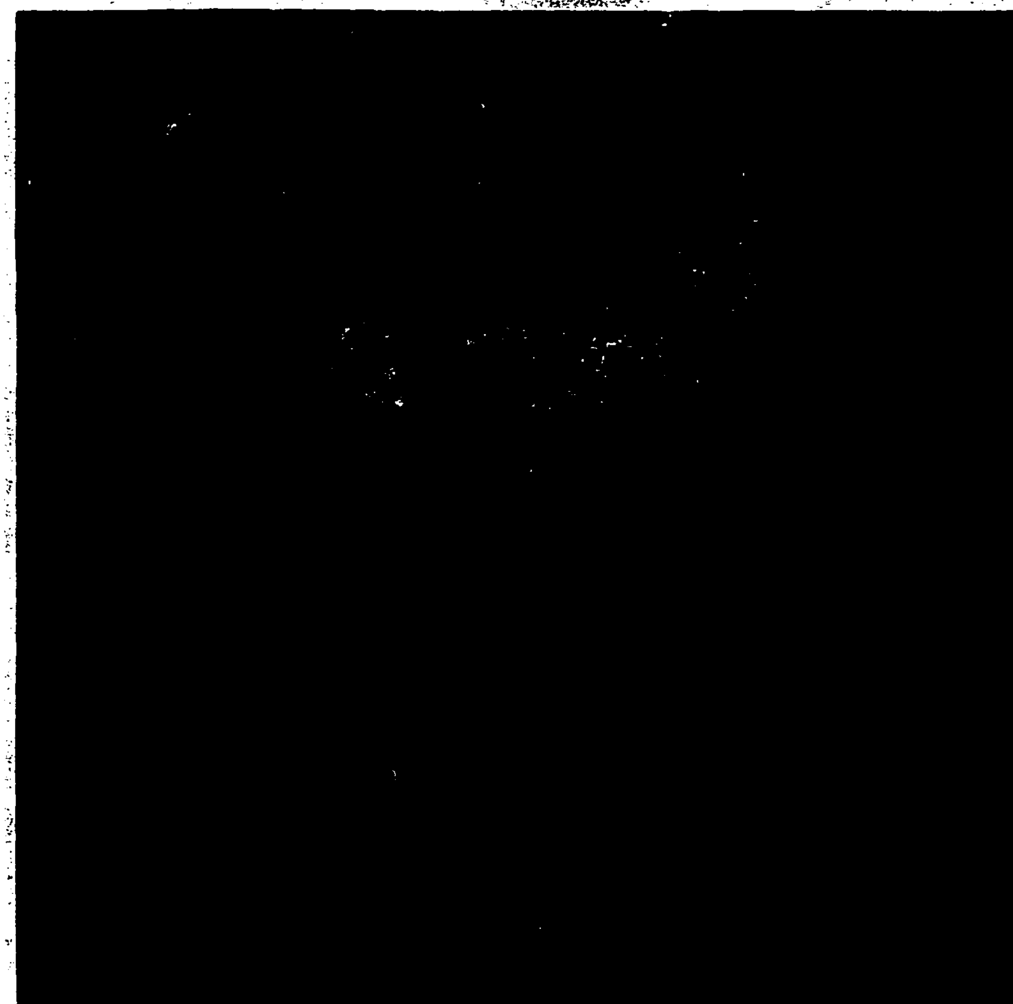
Test:	024 through 026 (1B-2) engine 018 6-18-64 to 6-20-64
Injector Type:	5867J3, U/N: X056, Aot: 58.8, Aft: 85.1, Vo(1500K): 138.9, Vf(1500K): 55.6
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees and orificed to half flow in axial feed holes); 0.242-inch diameter LOX doublets at 40 degrees (outer LOX ring is 0.209-inch diameter at 40 degrees, LOX holes next to baffle are 0.209-inch diameter at 40 degrees); 314 LOX splitters; 32 dams in the outer circumferential baffle and 8 dams in the inner circumferential baffle; no film or body coolant holes; 2.3 percent film coolant
Objective:	Investigation of performance, stability, and burning characteristics of this injector in the engine
Test Results:	All three tests were run with the nozzle extension installed. The first two tests were 80 and 115 seconds in duration, with I_s of 260.3 and 260.0 seconds, respectively. The only damage noted was erosion to the exit manifold and eight erosions on the shingles of the nozzle extension. The last test was bombed and incurred RCC after approximately 1.6 seconds. The bomb disturbance damped after 390 milliseconds. As a result of the prolonged instability, the thrust chamber developed three tube splits and several dented tubes near the injector end ring. Three external leaks also developed. The outer radial baffles were bent in a clockwise direction.
Frequency Analysis:	The mode of instability appeared to be of the resurging type coupled with 500-cps oscillations. Amplitudes were about 500 psi peak to peak with an out-of-phase condition existing across the oxidizer dome.

5. The effect of dams, in both the ring grooves and circumferential baffles, on the 500-cps buzz
6. The effect of changes in fuel atomization on the 500-cps buzz
7. Evaluation of the divergent ring concept
8. The effect of the low-differential-pressure dome on buzz
9. The effect of splitters on dynamic stability
10. Investigation of fuel buffered baffles
11. Investigation of canted oxidizer orifices adjacent to the radial baffles
12. The effect of reduced flow in the outer fuel ring on dynamic stability
13. Investigation of combustion chamber compatibility

Discussion. The numbers preceding the following paragraphs refer to the concepts listed above.

1. To determine whether complete isolation of the oxidizer dome would affect the 500-cps buzz, test 106 was conducted with injector unit X002 (Fig. 5). The hardware had been modified by the addition of four dome cavity radial dams that sealed against Teflon seals placed in grooves on the back of the injector. During the test, 500-cps buzzing self-initiated and increased in amplitude eventually causing a rough combustion cutoff. The instability damped but buzzing reinitiated, increased in amplitude, and retriggered into instability. Posttest inspection indicated that good sealing had been achieved.

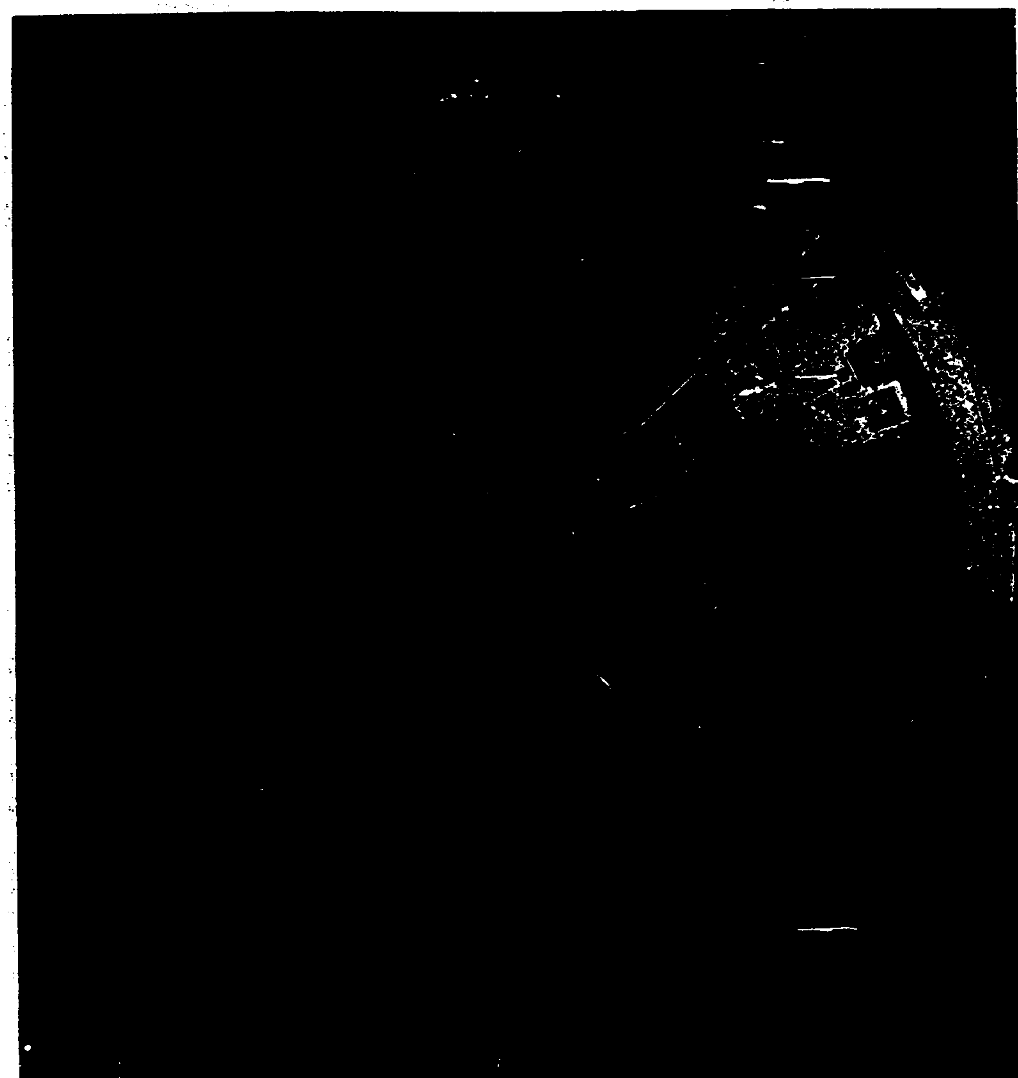
[redacted]



1DB45-3/30/64-C1B

Figure 5a. Injector Unit X002, Type 5855SS

[redacted]



1DB45-3/30/64-C1C

Figure 5b. Back Side of Injector Unit X002 Showing Grooves for Receiving Dome Cavity Dams

1DB45-4/13/64-C1B

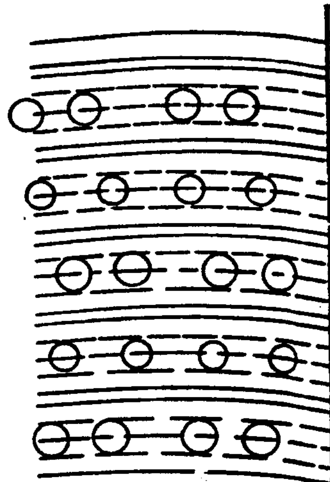
Figure 5c. View of Dome E001 Showing Dams

[redacted]

INJECTOR DESCRIPTION

UNIT X-002, TYPE 5855SS, S/N

ORIFICE PATTERN

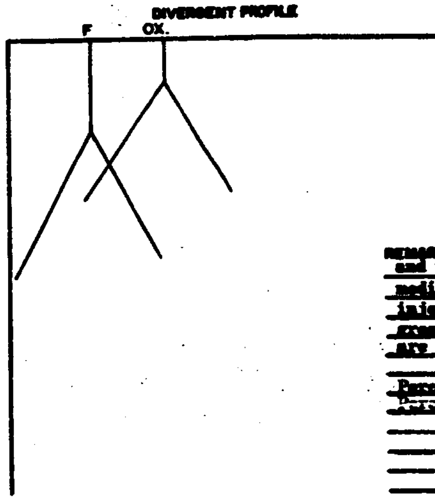


NO.	D	d	GROUP	Z	θ	Sp	X/c	Xμ
WALL	39.188							
	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
	34.506	0.209	88/96	0.374	28.2	1.13	0.349	0.153
	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

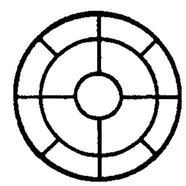
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	40.2
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj Velocity (1500%)	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector has deep LOX grooves and no film or body coolants; no hydraulic modification; LOX side is countersunk; the injector has 314 LOX splitters; also, has grooved back for the LOX side baffles, which are attached to the dome

Percent excess fuel on wall = 2.2
Percent film coolant = 4.61

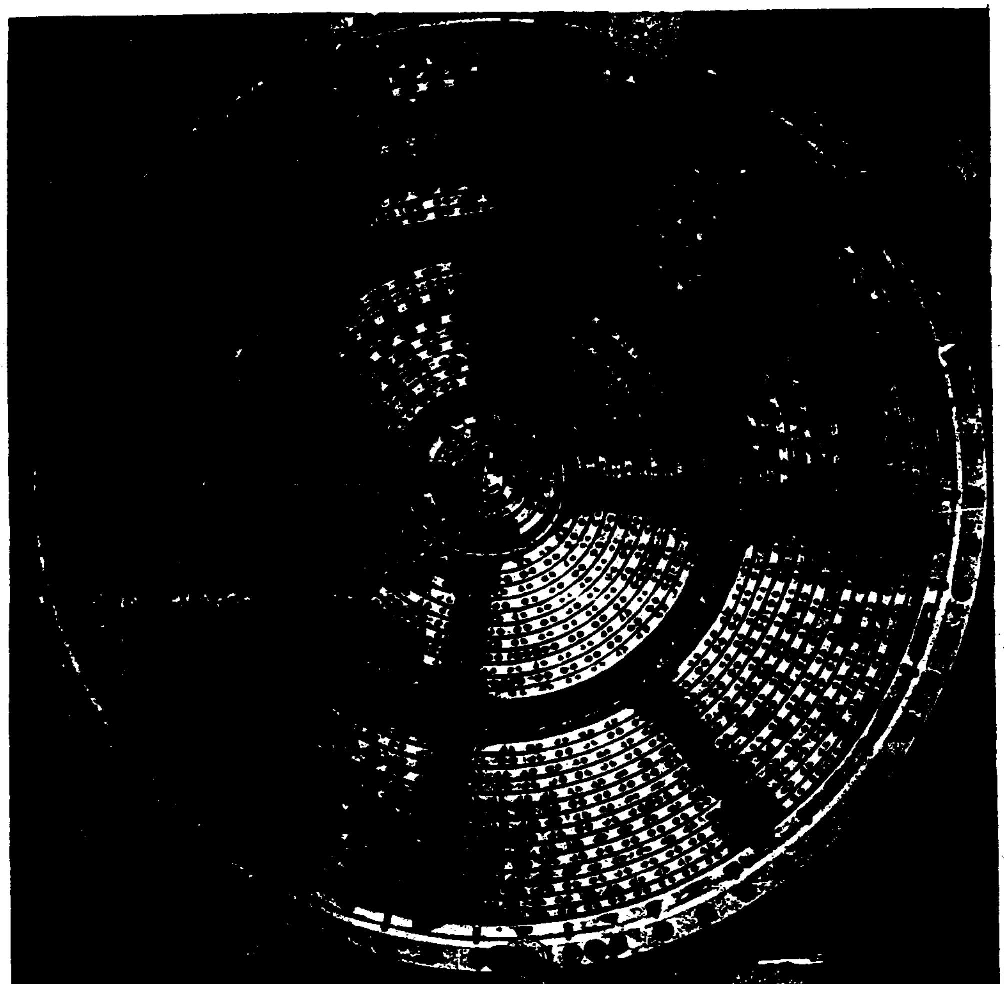
Figure 5d. Injector Description, Unit X002, Type 5855SS

[redacted]

2. Injector unit 081 (Fig. 6) was modified by enlarging the oxidizer orifices along the radial baffles. This was done to determine the effects of increased oxidizer along the radial baffles with respect to resurging and performance and to further lower oxidizer differential pressure. Tests 107 and 108 were conducted on injector unit 081 and the time required to damp bomb disturbances had increased from approximately 10 to 65 milliseconds. The performance of the configuration could not be successfully evaluated because of the brevity of the tests.

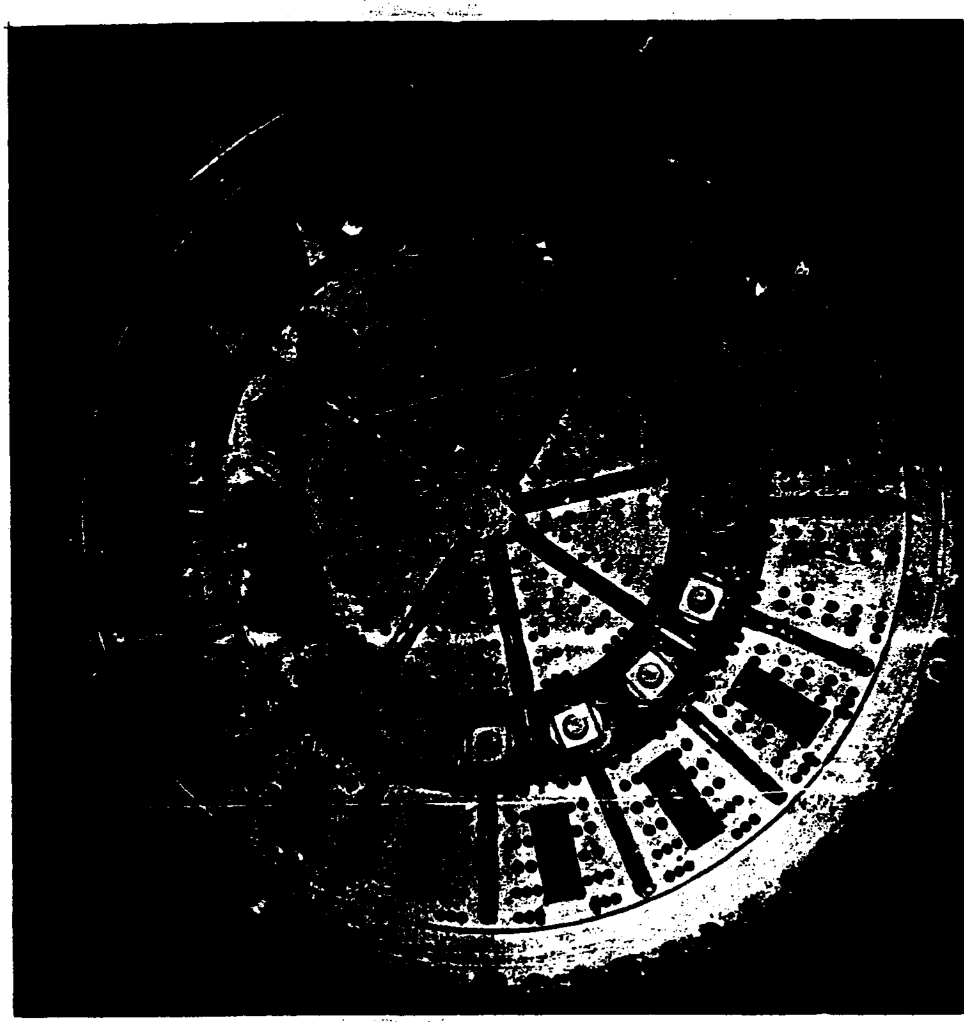
   Tests 117, 118, and 119 employed another modification of injector unit 081. All of the oxidizer doublets except those next to radial or circumferential baffles and those in the outer ring were further enlarged. In the first two tests, bombs induced resurging type instabilities which lasted for 288 and 240 milliseconds (there was no bomb on the third test). A performance gain of 3.5 percent η c* relative to tests 101 and 102 (Ref.: Vol. 2, Book 2) was realized with the modification.

3. The effects of reducing the size of oxidizer orifices on the 500-cps buzz mode were studied in test 114 with injector unit 075 (Fig. 7). The injector was modified such that the fuel orifice pattern was identical to injector unit 082 (Fig. 9, item 5) but the oxidizer pattern consisted of smaller, 0.199-inch diameter, orifices impinging at 56 degrees 24 minutes. No bomb was employed in the test and the system ran for programmed duration despite the fact that 500-cps buzzing persisted at a moderate amplitude throughout the entire mainstage portion of the run. Oscillations were noted in both the feed system and chamber parameters.



1DB45-4/1/64-C1A

Figure 6. Injector Unit 081, Type 5862TT



1DB45-4/1/64-C1B

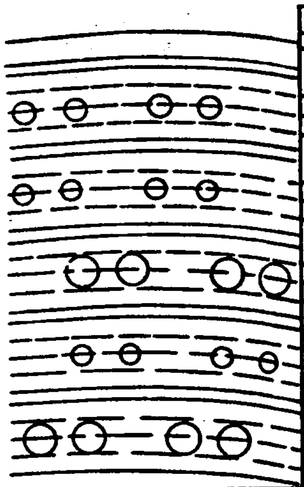
Figure 6. (Continued)

[redacted]

INJECTOR DESCRIPTION

UNIT 081, TYPE 5862TT, S/N

ORIFICE PATTERN

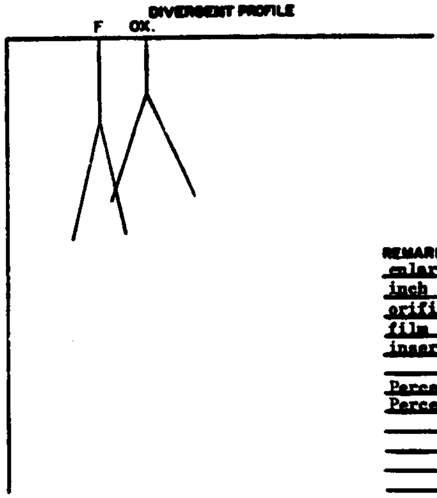


NO.	D	d	GROUP	Z	θ	Sp	Xjo	Xjf
WALL	39.188							
--	37.981							
-59	37.766	0.228	96/104	0.416	20°	1.1[illegible]	[illegible].571	0.258
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.282
-55	35.626	0.281	88/96	0.428	15°	1.17	0.794	0.274
-53	34.506	0.209	88/96	0.416	20°	1.13	0.571	0.282
-51	33.386	0.281	80/88	0.428	15°	1.22	0.794	0.274

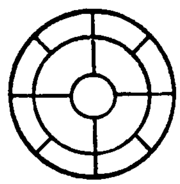
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.12	49.2
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Velocity (1500K)	55.7	169

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES

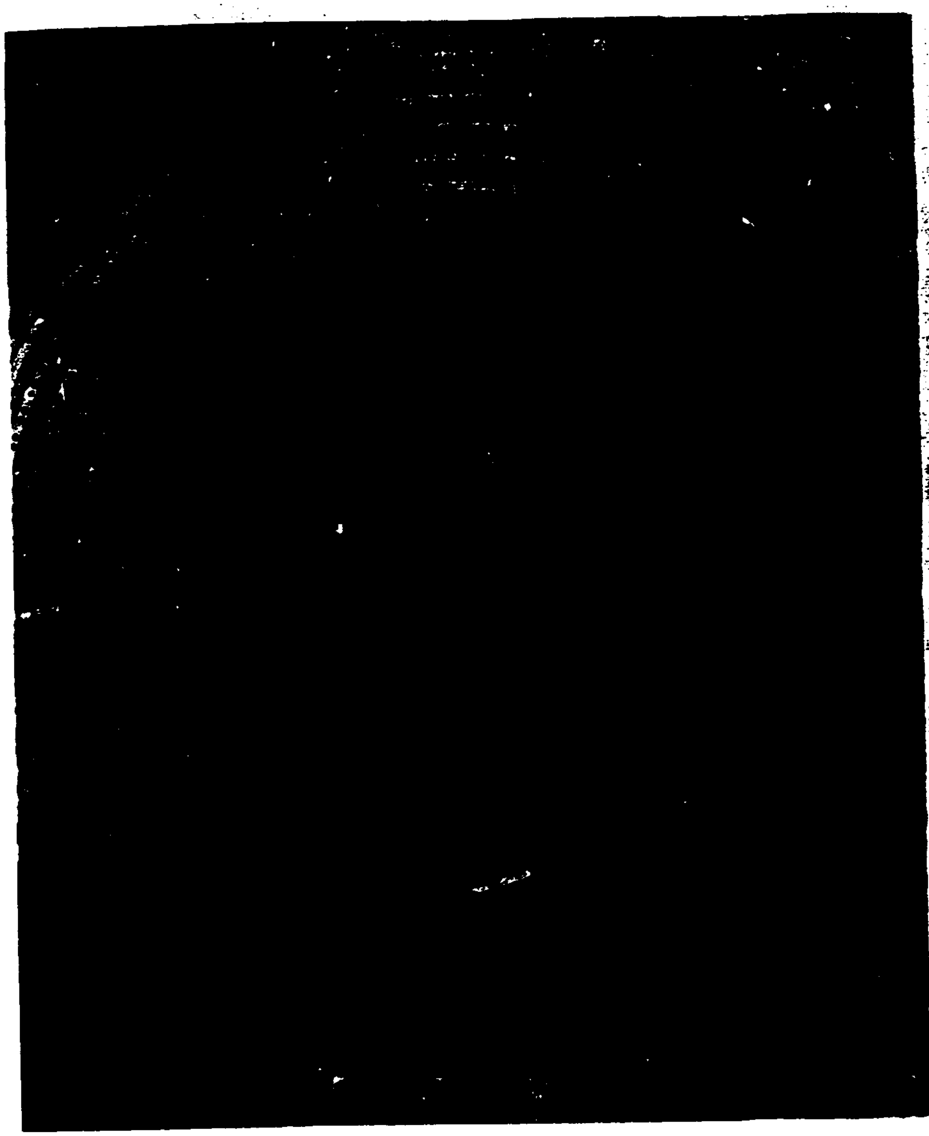


REMARKS: Injector modification consisted of enlarging remaining LOX orifices to 0.209-inch diameter. The outer fuel ring remains orificed for 50 percent flow. All body and film coolants remain plugged. No fuel port inserts.

Percent excess fuel = 2.20
Percent film coolant = 4.6

Figure 6. (Concluded)

[redacted]



1DB41-4/6/64-C1D

Figure 7. Injector Unit 075, Type 5865WW

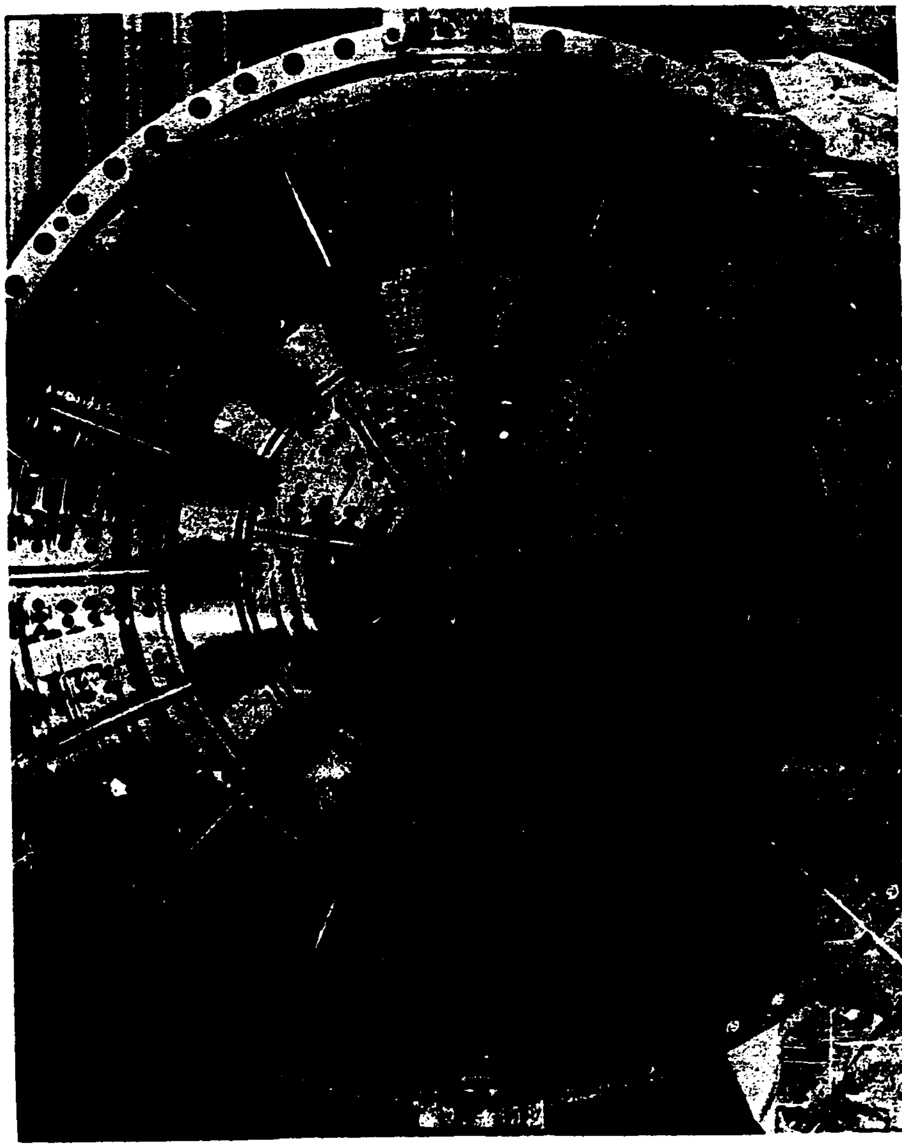


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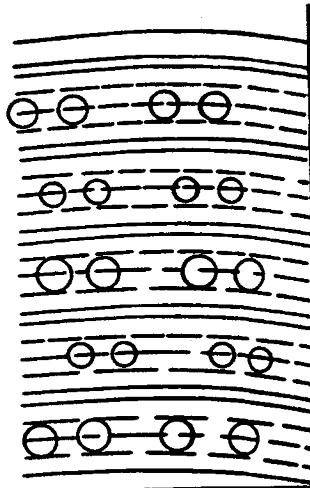
Figure 7. (Continued)

[redacted]

INJECTOR DESCRIPTION

UNIT 075, TYPE 586[illegible], S/N

ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.199	96/104	0.374	28.2	1.11	0.349	0.163
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.306	0.199	88/96	0.374	28.2	1.13	0.349	0.163
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

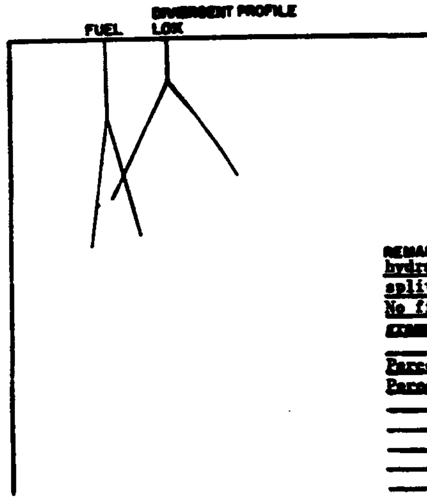
PATTERN, GENERAL

	FUEL	OXID.
ORIFICE AREA	84.8	44.6
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RINGS)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Velocity (1500K)	55.9	183.2

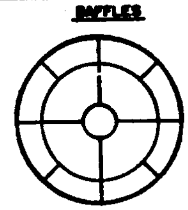
BAFFLE DESIGN

NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: LOX orifices countersunk; no hydraulic modification except 314 LOX splitters; and 32 fuel port isolation tabs; No film or body coolants; also, has pre-grooved baffles

Percent film coolant = 4.6

Percent excess fuel on wall = 2.2

Figure 7. (Concluded)

[redacted]

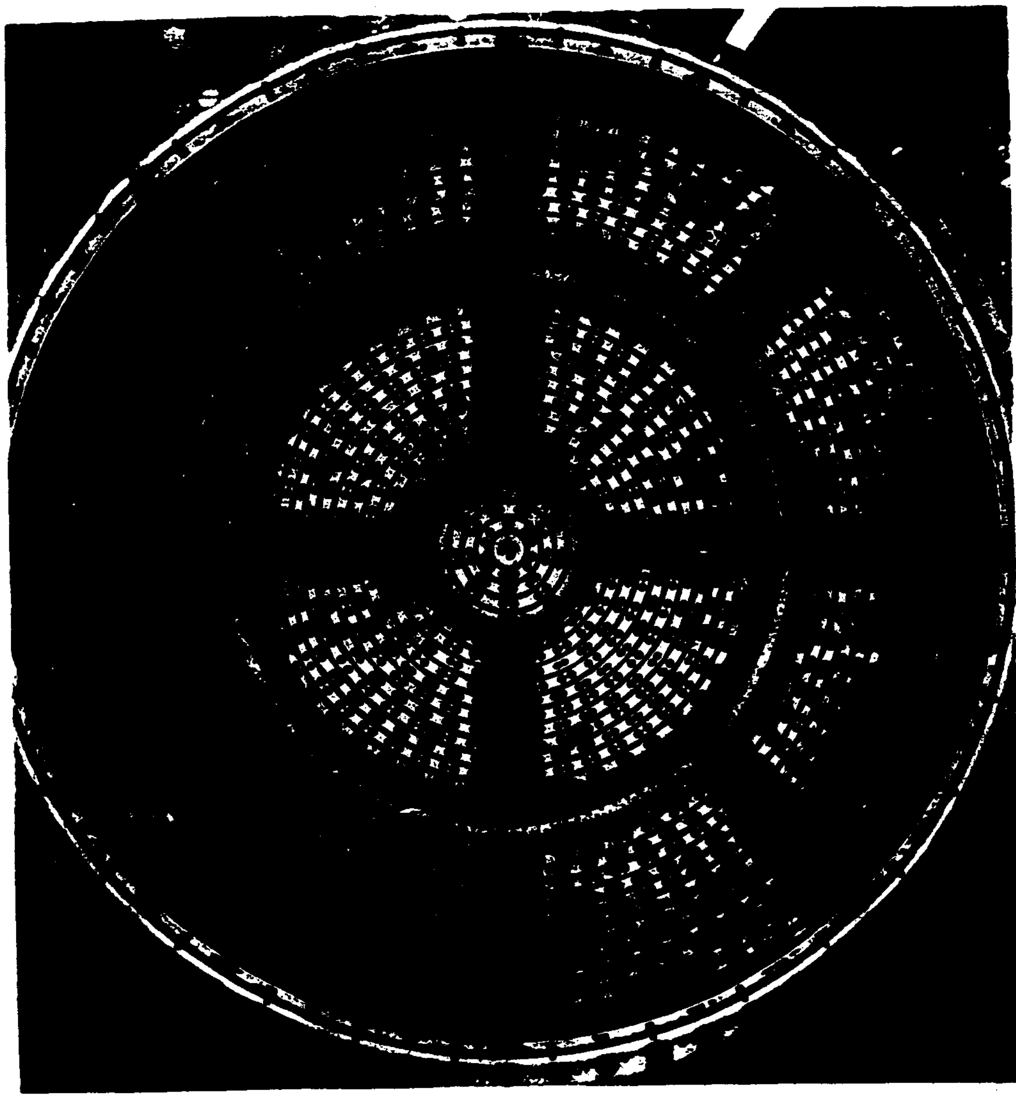
4. The outer LOX and fuel rings of injector unit X040 (Fig. 8) were plugged and a single test was conducted without a bomb. The plugging of the outer two rings appeared to be beneficial in suppressing the 500-cps buzz mode. The Brush records indicated no significant amount of 500-cps oscillations present in any parameters.

5. Several series of tests were conducted to determine the effects of ring groove and baffle dams on the 500-cps buzz mode.

   Three tests were conducted on injector unit 082 (Fig. 9) with 156 dams in the fuel ring grooves. Four bomb disturbances in first two tests damped within 7 milliseconds. Analysis of Brush records and power spectral density plots revealed that 500-cps oscillations were present only in the fuel system, and these were of very low amplitude. Injector unit 082 was then modified by placing 8 dams in the inner circumferential baffle. Two tests were then conducted. Based on Brush records, there were no indications of 500-cps buzz in any parameters for the first test, but the bomb disturbances induced slight indications of buzz in the seond test. The damp times were 5 and 10 milliseconds.

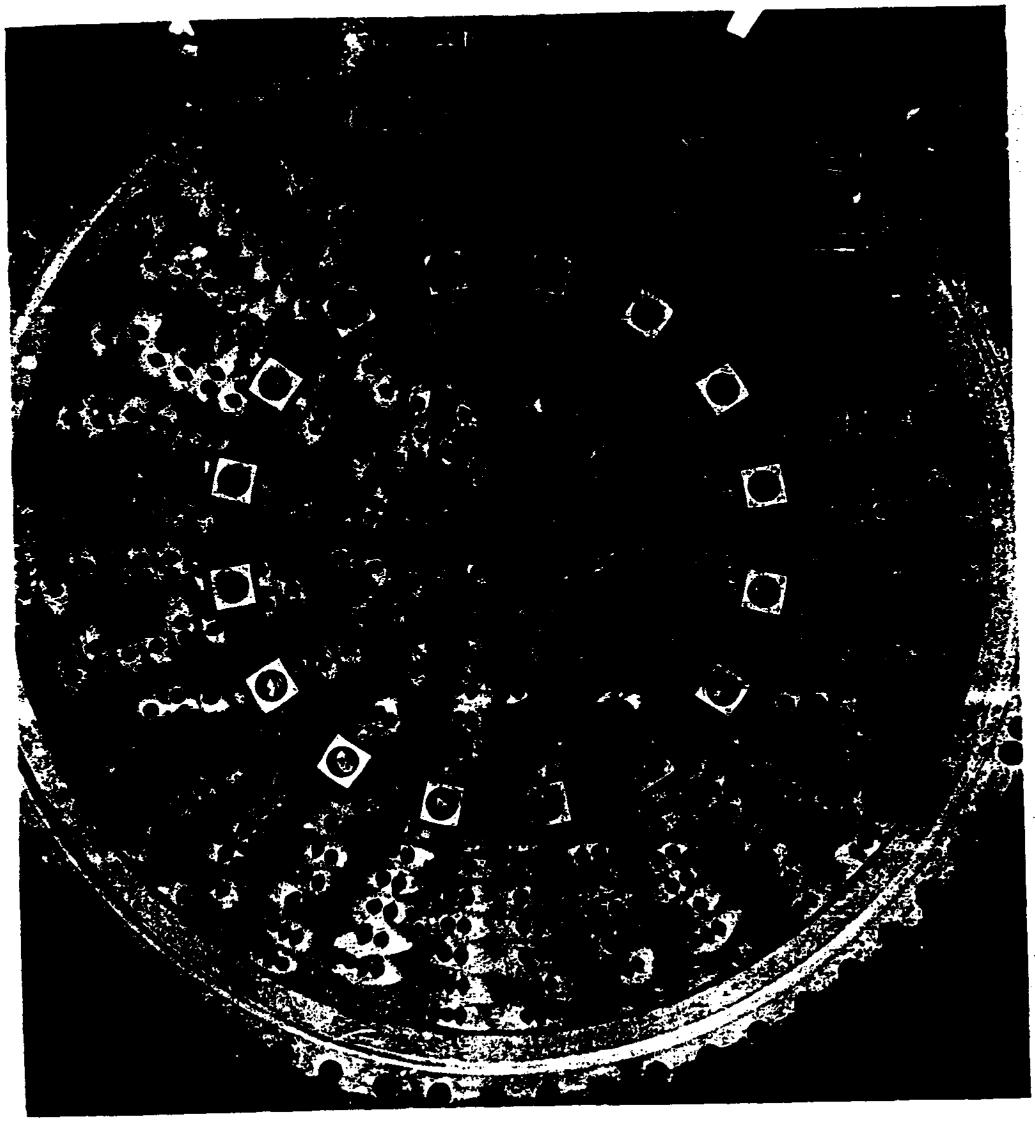
   Dams were also placed in the fuel ring grooves and circumferential baffle cavities of injector X002, and two tests were conducted. Although these modifications successfully eliminated the buzz in injector unit 082, there was no apparent charge in the buzz of injector unit X002. In both tests, the system self-triggered in the 500-cps buzz mode and an RCC resulted. Both tests were too short to acquire steady-state data.

6. To study the effects of changes in fuel atomization, one test was conducted on injector unit X011 (Fig. 10). The injector had an oxidizer pattern identical to injector unit 082 (Fig. 9).



1DB41-4/3/64-C1A

Figure 8. Injector Unit X040, Type 5863PP



1DB41-4/3/64-C1B

Figure 8. (Continued)

[redacted]

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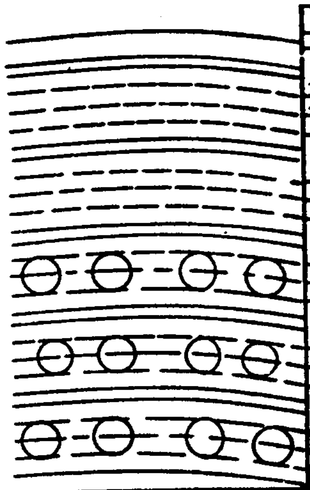
INJECTOR DESCRIPTION

UNIT X-040, TYPE 5863PP, S/N

ORIFICE PATTERN

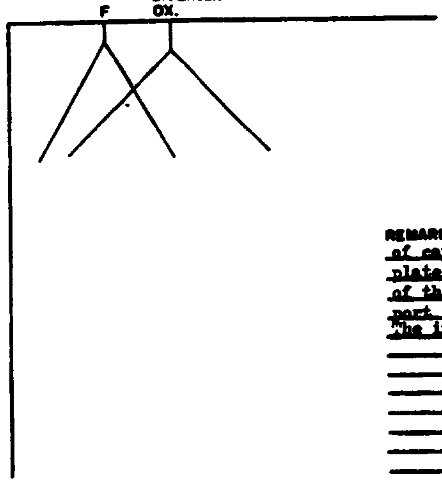


NO.	D	d	GROUP	Z	θ	Sp	Xjs	Xji
WALL	38.188							
-								
-59	37.776							
-57	36.746							
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.254
-53	34.506	0.238	88/96	0.304	38°	1.13	0.195	0.042
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.254

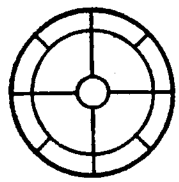
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	77.30	51.5
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	2.442	
WALL GAP (OUTER ZONE)		
Inj Velocity (1500K)	61.3	159

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES

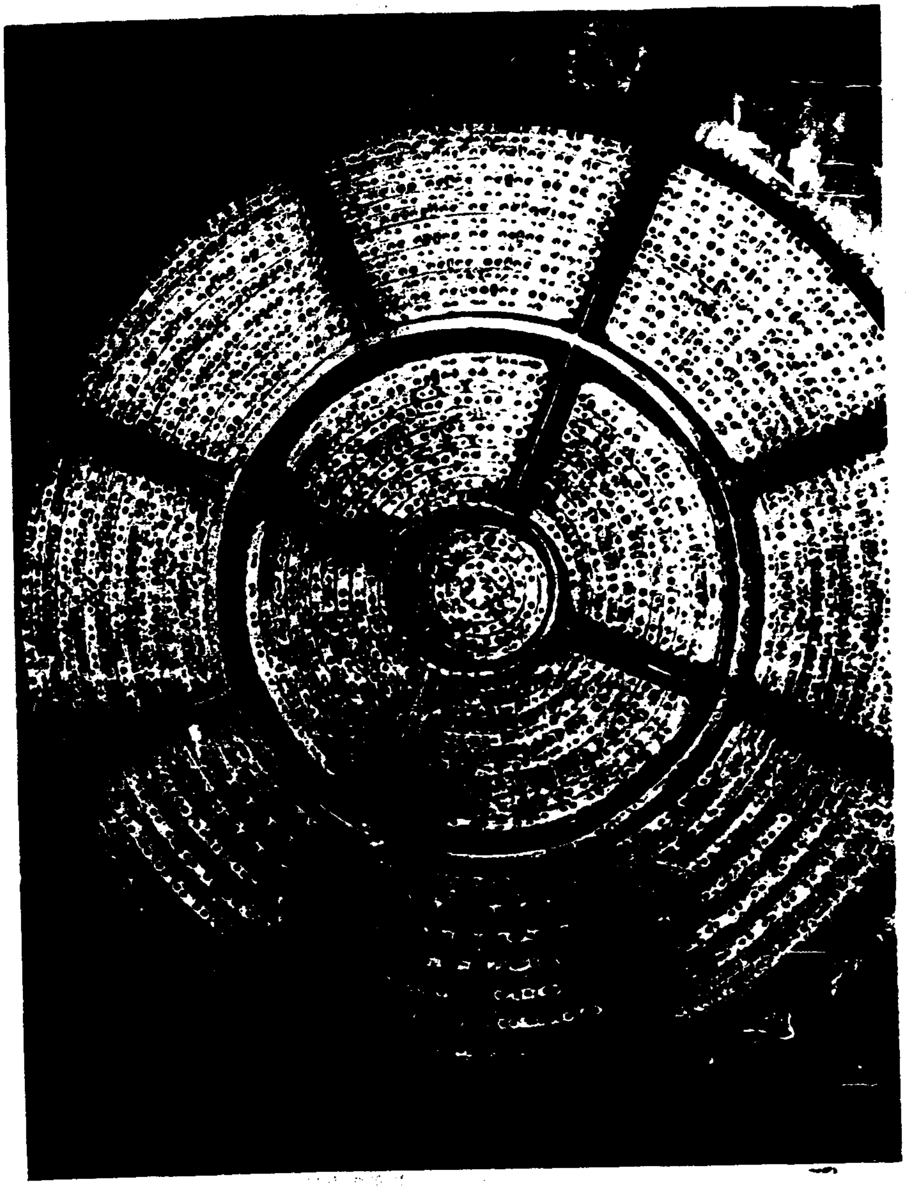


REMARKS: The injector modification consisted of capping the outer two rings with cover plates. The LOX ring on the outboard side of the outer can remains plugged. The fuel port isolation tabs remain on the injector. The injector has 340 splitters.

Figure 8. (Concluded)

[redacted]

[redacted]



1DB45-4/4/64-E1

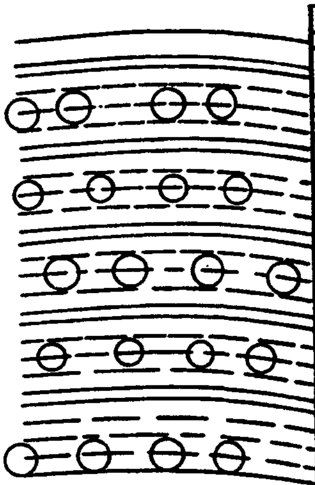
Figure 9. Injector Unit 082, Type 5833UU

[redacted]

INJECTOR DESCRIPTION

UNIT 082, TYPE 5833UT, S/N

ORIFICE PATTERN

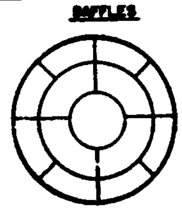


NO.	D	ℓ	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
	37.256							
	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
	34.506	0.209	88/96	0.374	28.2	1.13	0.349	0.153
	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

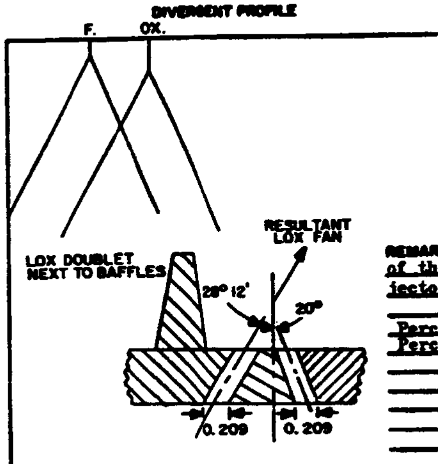
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.08	49.2
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Vel. (1500K)	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

BAFFLES



DIVERGENT PROFILE

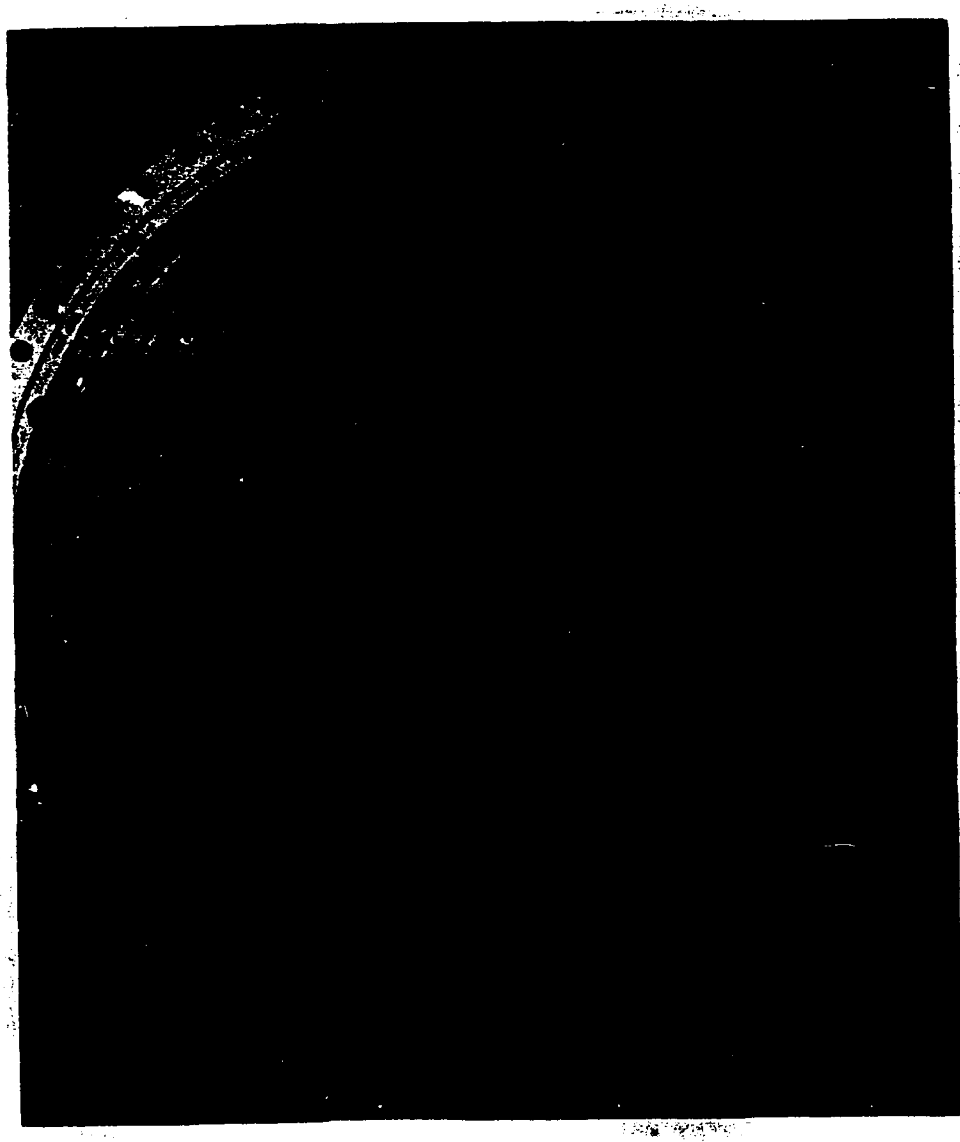


REMARKS: The injector modification consisted of the addition of fuel ring dams. The injector has 314 LOX splitters.

Percent excess fuel in outer periphery = 2.22
Percent film coolant - 4.62

Figure 9. (Concluded)

[redacted]

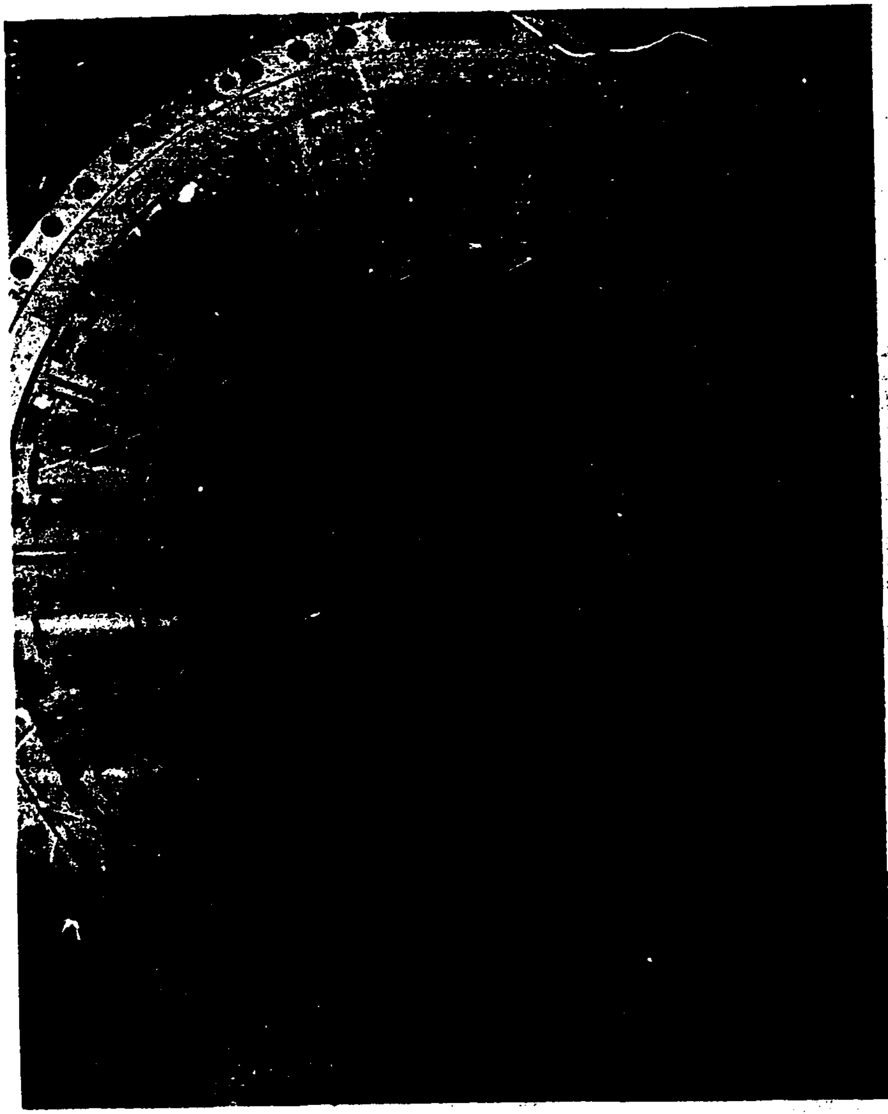


1DB41-4/6/64-C1C

Figure 10. Injector Unit X011, Type 5864VV

[redacted]

[redacted]



1DB41-4/6/64-C1F

Figure 10. (Continued)

[redacted]

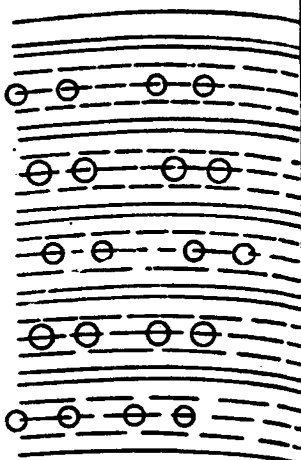
[redacted]

ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

INJECTOR DESCRIPTION

UNIT X011, TYPE 5864VV, S/N

ORIFICE PATTERN

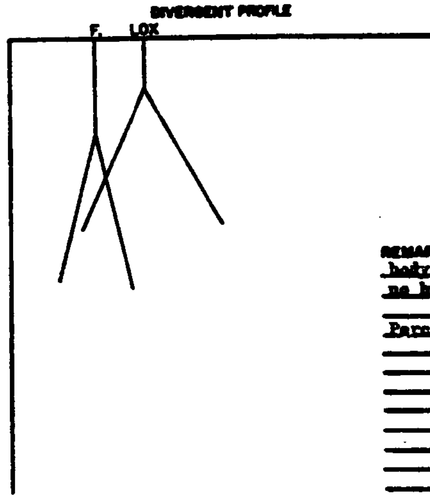


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
	37.776	0.159	96/104	0.416	20°	1.14	0.571	0.353
	36.746	0.209	96/104	0.374	28.2	1.11	0.391	0.172
	35.626	0.159	88/96	0.416	15°	1.17	0.776	0.479
	34.506	0.209	88/96	0.374	28.2	1.13	0.391	0.172
	33.386	0.159	80/88	0.416	15°	1.17	0.776	0.479

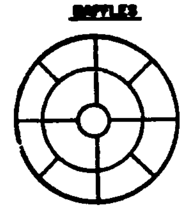
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	30.0	49.2
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj.Velocity(1500K)	154.7	166.1

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: LOX orifices countersunk: the injector body has deep LOX grooves: the injector has no hydraulic modification except for splitters

Percent film coolant = 6.3

Figure 10. (Concluded)

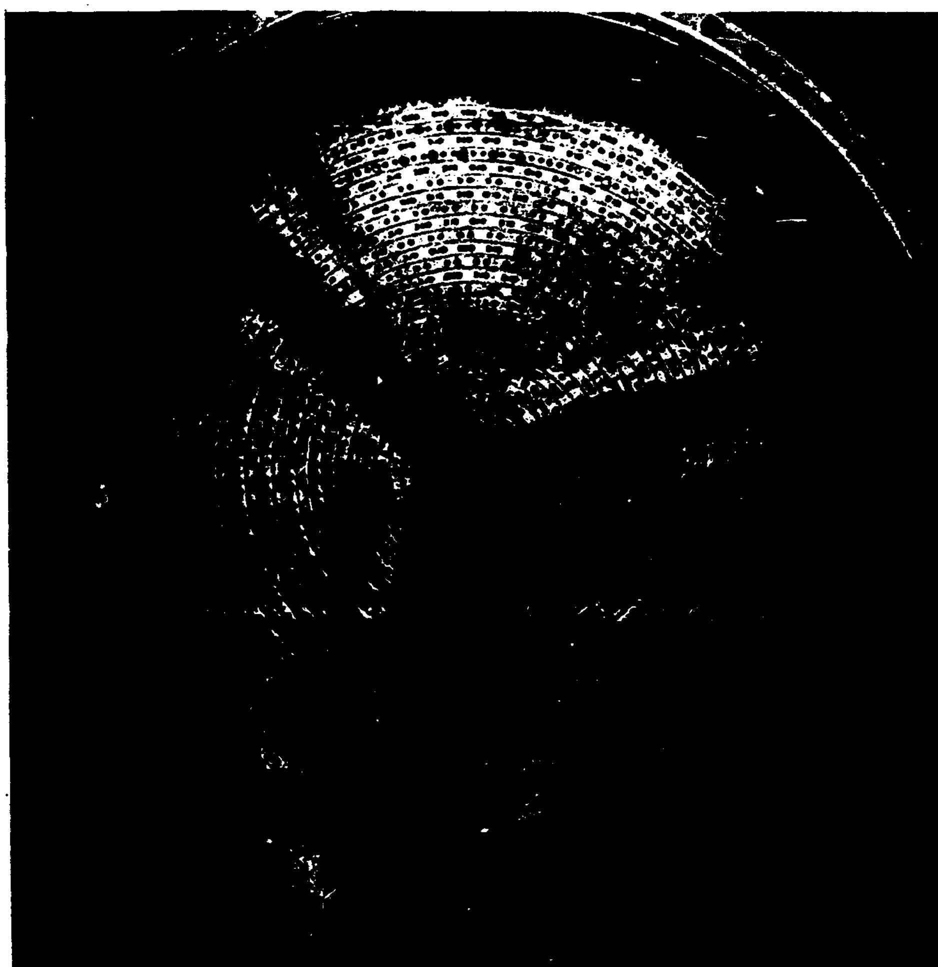
[redacted]

The fuel pattern consisted of 0.159-inch-diameter fuel doublets impinging at 40 degrees. During the test, immediately after mainstage operation was reached, a series of rapidly diverging 500-cps oscillations commenced. These were followed by the appearance of higher frequency components. A rough combustion cutoff resulted. It was evident that to maintain stability, large fuel orifices must be used.

7. The divergent ring concept was evaluated again with reduced oxidizer along the radial baffles. Two tests were conducted on injector unit R007 (Fig. 11). The configuration consisted of three baffle compartments, a six-ring divergence, and all oxidizer triplets next to the baffles blanked. In the first test, the bomb disturbance damped in 12 milliseconds. However, in the second test the bomb induced a low-amplitude cyclic instability which caused a rough combustion cutoff. The oscillations persisted for 565 milliseconds and appeared to contain frequencies of 1250, 250, and 500 cps.

8. During this period, an oxidizer dome, which was modified by the addition of streamlined inlets to reduce the pressure drop from the inlets to the oxidizer cavity, was tested. One test, with injector unit X002, resulted in a rough combustion cutoff. Reliable test data were not obtained because of the short test duration. Three more tests were conducted with injector unit 082. The first test, conducted without a bomb, exhibited a low-amplitude, out-of-phase, 400-cps buzz in all parameter throughout the entire mainstage portion of the run. In the second test there were no clear frequencies discernible in any parameter. The third test employed two bombs and resulted in a rough combustion cutoff. The test exhibited some low-amplitude intermittent buzzing in fuel parameters after the bomb disturbances.

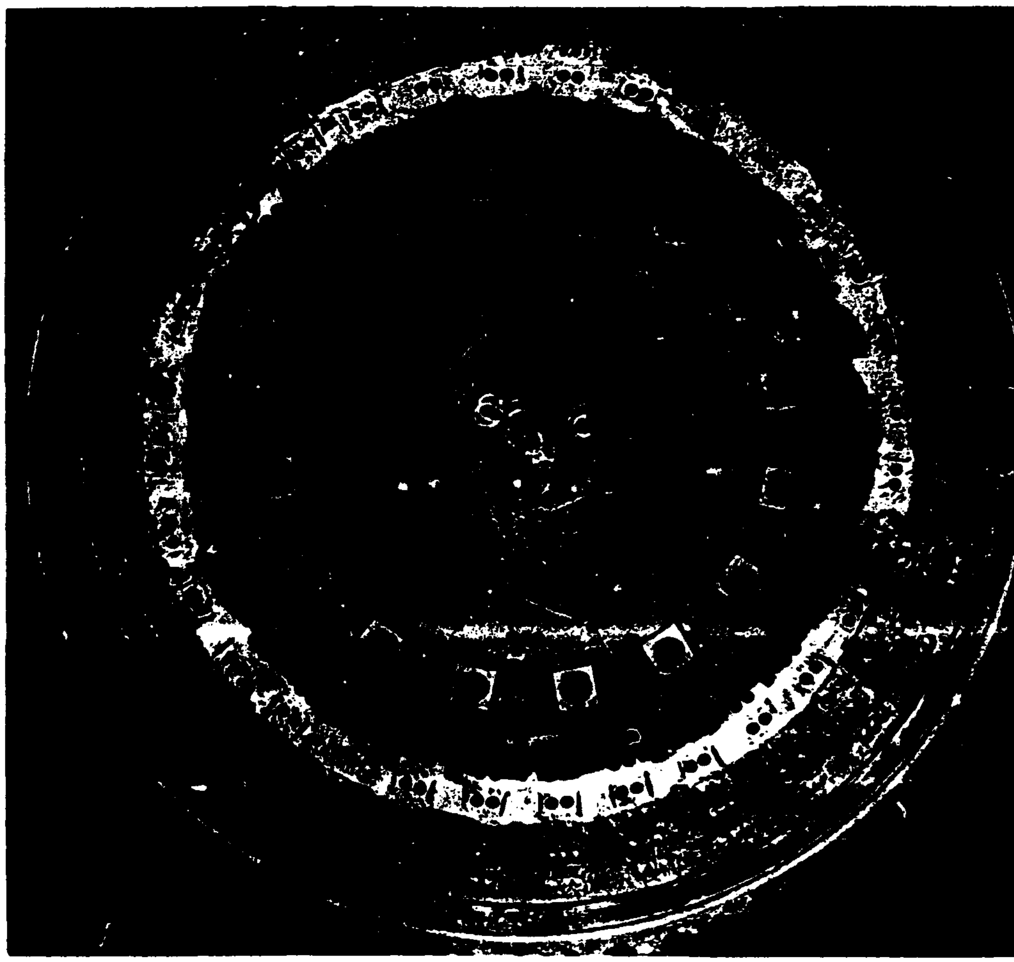
[redacted]



1DB45-4/7/64-C1A

Figure 11. Injector Unit R007, Type 5866X

[redacted]



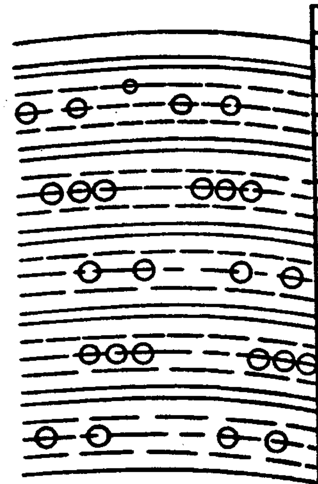
1DB45-4/7/64-C1B

Figure 11. (Continued)

INJECTOR DESCRIPTION

UNIT R007 , TYPE 5866X , S/N

ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjs	Xji
WALL								
		0.089	71/75					
-57	31.146	0.2055	72/75	0.416	20°	1.21	0.571	0.288
		0.238						
-55	30.026	0.204 sh.hd	72/75	0.416	20°	1.17	0.571	0.245
-53	28.906	0.221	69	0.416	20°	1.21	0.571	0.268
-51	27.786	0.238 0.204 sh.hd	66	0.416	20°	1.16	0.571	0.245
-49	26.660	0.221	60	0.416	20°	1.22	0.571	0.268

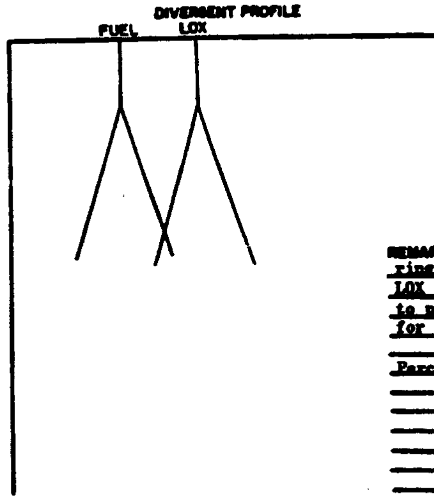
PATTERN, GENERAL

	FUEL	OXID.
ORIFICE AREA	37.11	56.9
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.176	
WALL GAP (OUTER ZONE)	4.021	
Inj.Velocity (1500K)	128	136

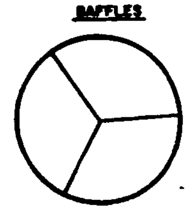
BAFFLE DESIGN

NUMBER OF COMPARTMENTS	3
BAFFLE CONSTRUCTION	2-inch base
BAFFLE COOLANT	None
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Divergent ring placed over outer six rings; the baffles are uncooled; 14 additional LOX triplets were blanked along the baffles to provide the same oxidizer pattern as used for the eight-ring divergent injector

Percent film coolant = 7.6

Figure 11. (Concluded)

[redacted]

The bomb disturbances were damped in 28 and 8 milliseconds which, coupled with ignition start, were enough for an RCC based on accumulated count. It was concluded that the low-differential-pressure oxidizer dome did not have any effect on buzz.

9. To determine the effects of oxidizer feed passage splitters, tests were conducted with injector unit 081. The injector had 314 oxidizer feed passage splitters installed. The tests were conducted in a solid-wall chamber. Six bomb disturbances were damped in less than 14 milliseconds, and there was no evidence of 500-cps buzzing.

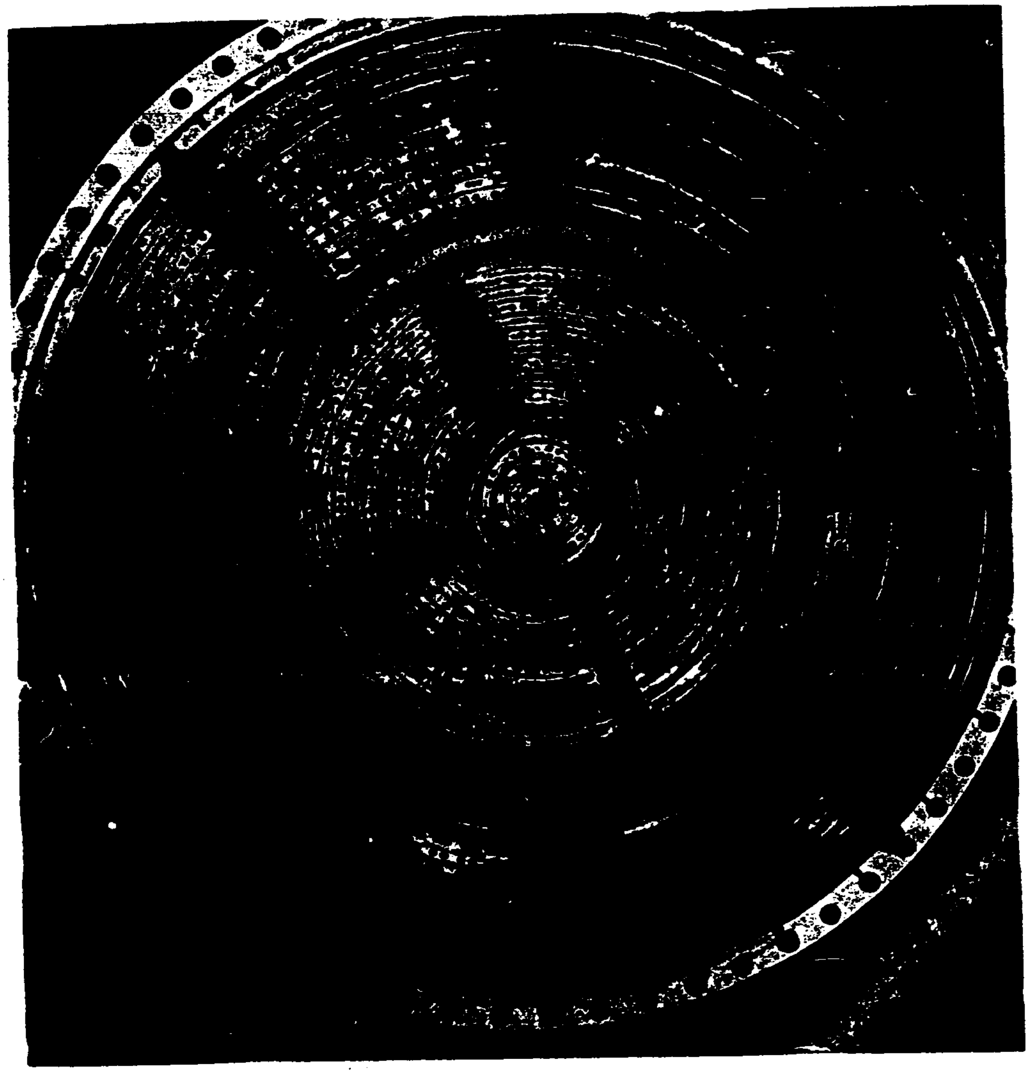
   A test was conducted on unit X007A (Fig. 12) to determine the effect of removing 32 oxidizer feed passage splitters on resurging. The test was bombed and the instability persisted for 287 milliseconds and caused a rough combustion cutoff. The mode of instability was resurging with 480- to 500-cps oscillations present in oxidizer and fuel parameters.

   In general, it appeared that the oxidizer feed passage splitters tended to suppress the 500-cps oscillations.

10. Three tests were conducted on injector unit X035 to investigate the effect of fuel buffered baffles on stability. The injector was an uncooled, tri-baffled configuration with 38 oxidizer triplets plugged along the baffles (Fig. 13). Previously, this system, without the plugged oxidizer groups along the baffles, exhibited a high-amplitude, 500-cps roughness, which caused immediate RCC. During this test series, three bomb induced disturbances were damped in 12 milliseconds or less. This indicated that fuel along the baffles was beneficial for stability.

[redacted]

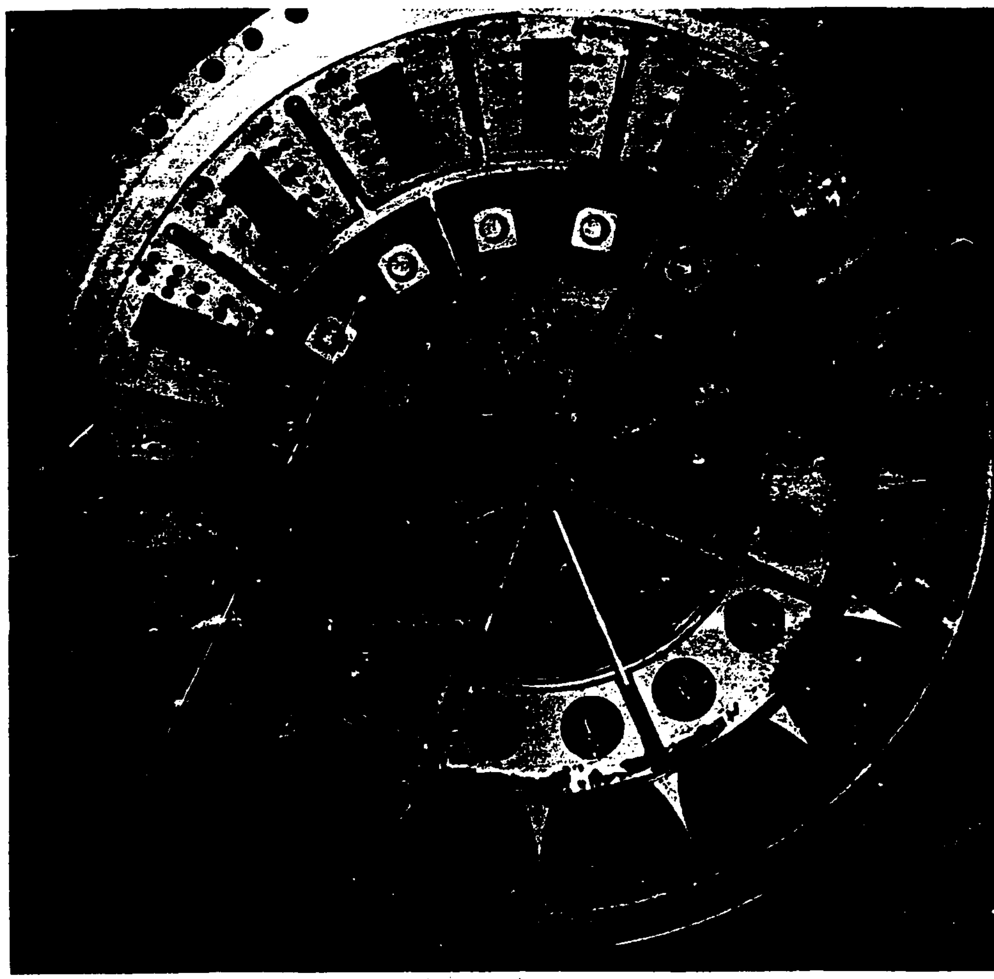
[redacted]



1DB45-8/25/64-C1A

Figure 12. Injector Unit X007A, Type 5830XX

[redacted]



1DB45-8/25/64-C1B

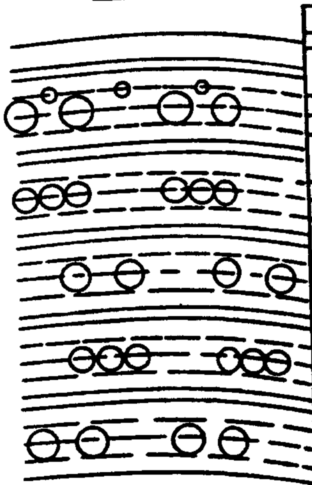
Figure 12. (Continued)

[redacted]

INJECTOR DESCRIPTION

UNIT X007A , TYPE 5830XX , S/N

ORIFICE PATTERN

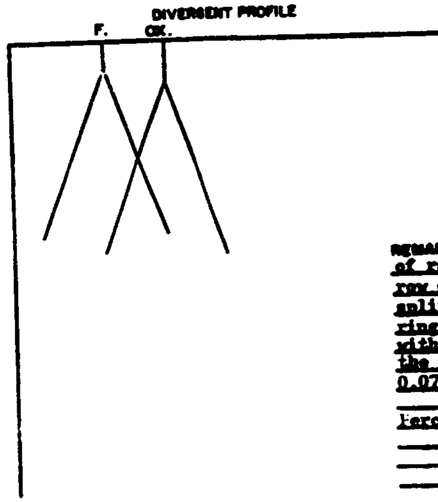


NO.	D	d	GROUP	Z	θ	Sp	Xjs	Xji
WALL	39.188							
	37.961	0.154	184/200	—				
	37.776	0.228	46/104	0.416	20°	1.14	0.571	0.176
	36.746	0.185	96/104	0.416	20°	1.11	0.5	317
	35.626	0.228	88/96	0.416	20°	1.17	0.571	0.176
	34.506	0.185	88/96	0.416	20°	1.13	0.571	0.317
	33.386	0.228	80/88	0.416	20°	1.19	0.571	0.176

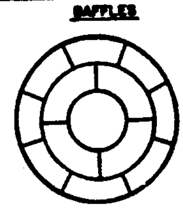
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	63.33	53.3
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Vel. (1500K)	74.8	153.5

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



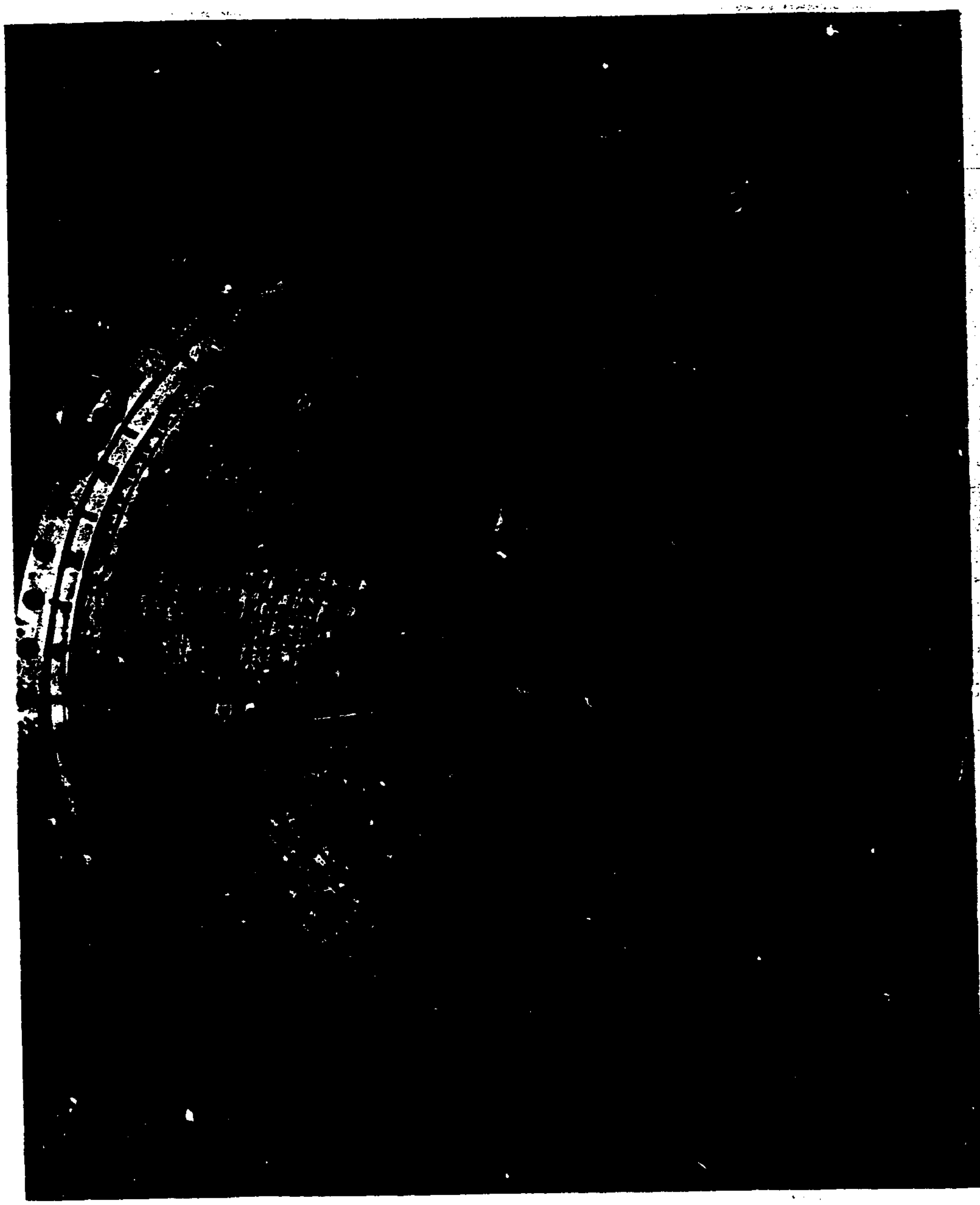
REMARKS: The injector modification consisted of removing the 32 LOX splitters in the outer row of axial feed holes. There are no LOX splitters in the injector; only the 32 fuel ring dams. Injector remains a modification II without flame suppressors or ASME orifices in the outer two rings; 100 body coolants at 0.076-inch diameter

Percent film coolant = 14.1

Figure 12. (Concluded)

[redacted]

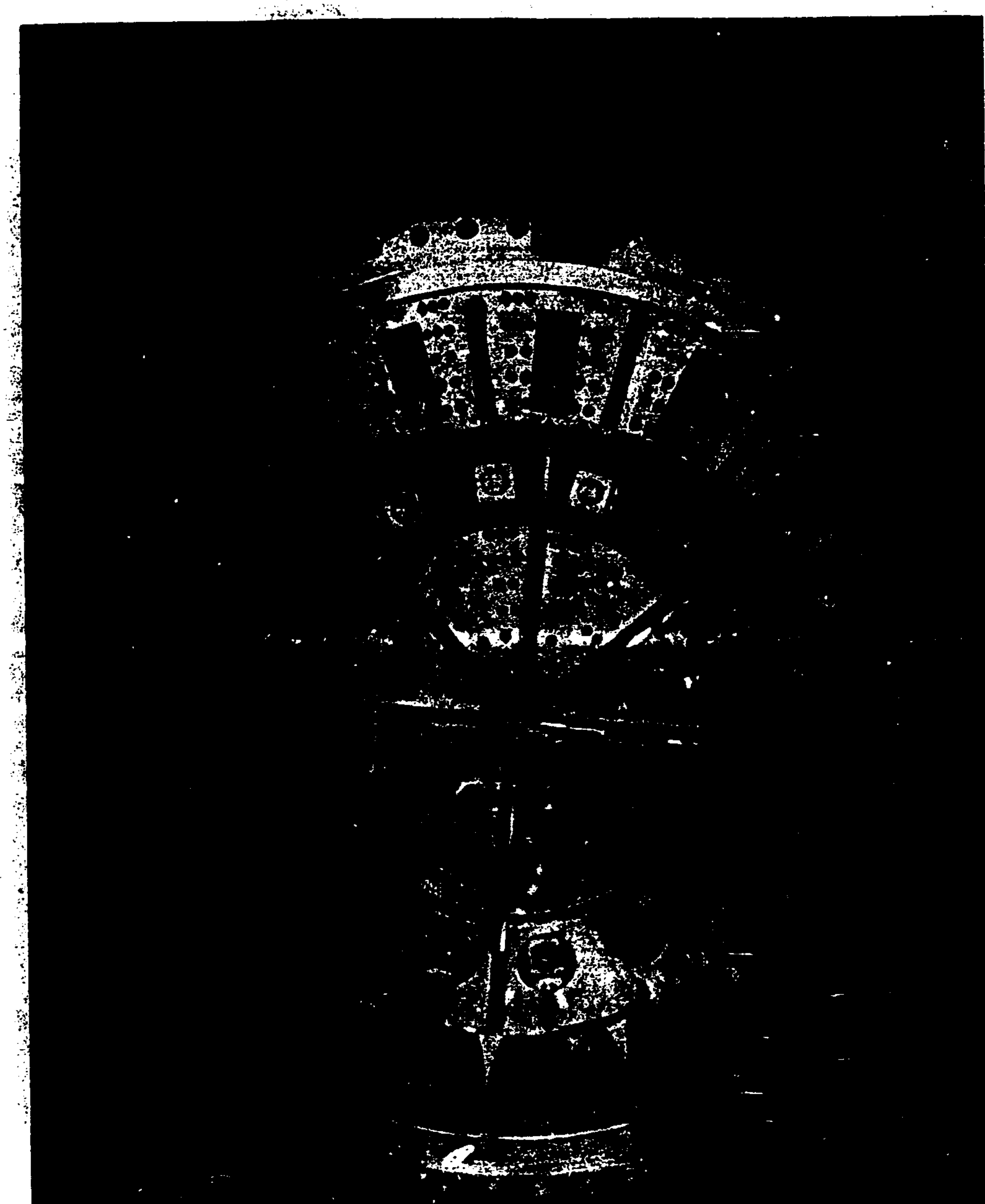
[redacted]



1DB45-4/20/64-C1C

Figure 13. Injector Unit X035, Type 5869R

[redacted]



1DB45-4/20/64-C1D

Figure 13. (Continued)

[redacted]

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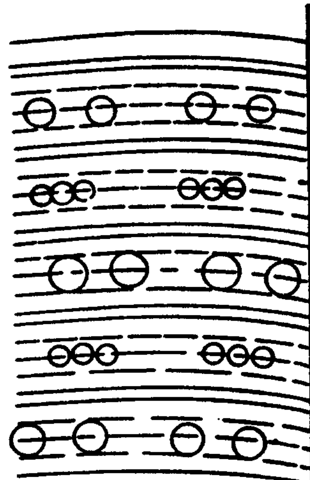
INJECTOR DESCRIPTION

UNIT X035, TYPE 5869R, S/N

ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xμ
WALL	39.188							
-69	37.776	0.228	93/100	0.416	20°	1.19	0.571	0.258
-67	36.746	0.159	93/100	0.416	20°	1.15	0.571	0.353
-65	35.626	0.281	86/94	0.416	15°	1.19	0.744	0.252
-63	34.506	0.159	84/94	0.416	20°	1.16	0.571	0.353
-61	33.386	0.281	80/87	0.416	15°	1.21	0.744	0.252

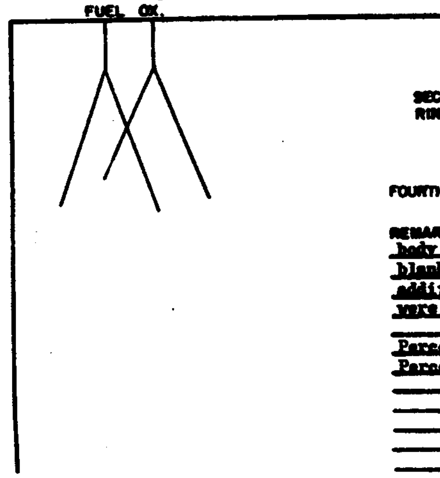
PATTERN, GENERAL

	FUEL	OXID.
ORIFICE AREA	86.20	41.90
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Vel. (1500K)	55	195

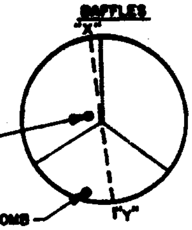
BAFFLE DESIGN

NUMBER OF COMPARTMENTS	3
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	None
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Standard 5U pattern; blanked film and body coolant holes; six igniter buttons blanked; like X035, 5834R except that 17 additional LOX triplets next to the baffles were blanked

Percent excess fuel on wall = 2.1

Percent Film Coolant = 4.4

Figure 13. (Concluded)

[redacted]

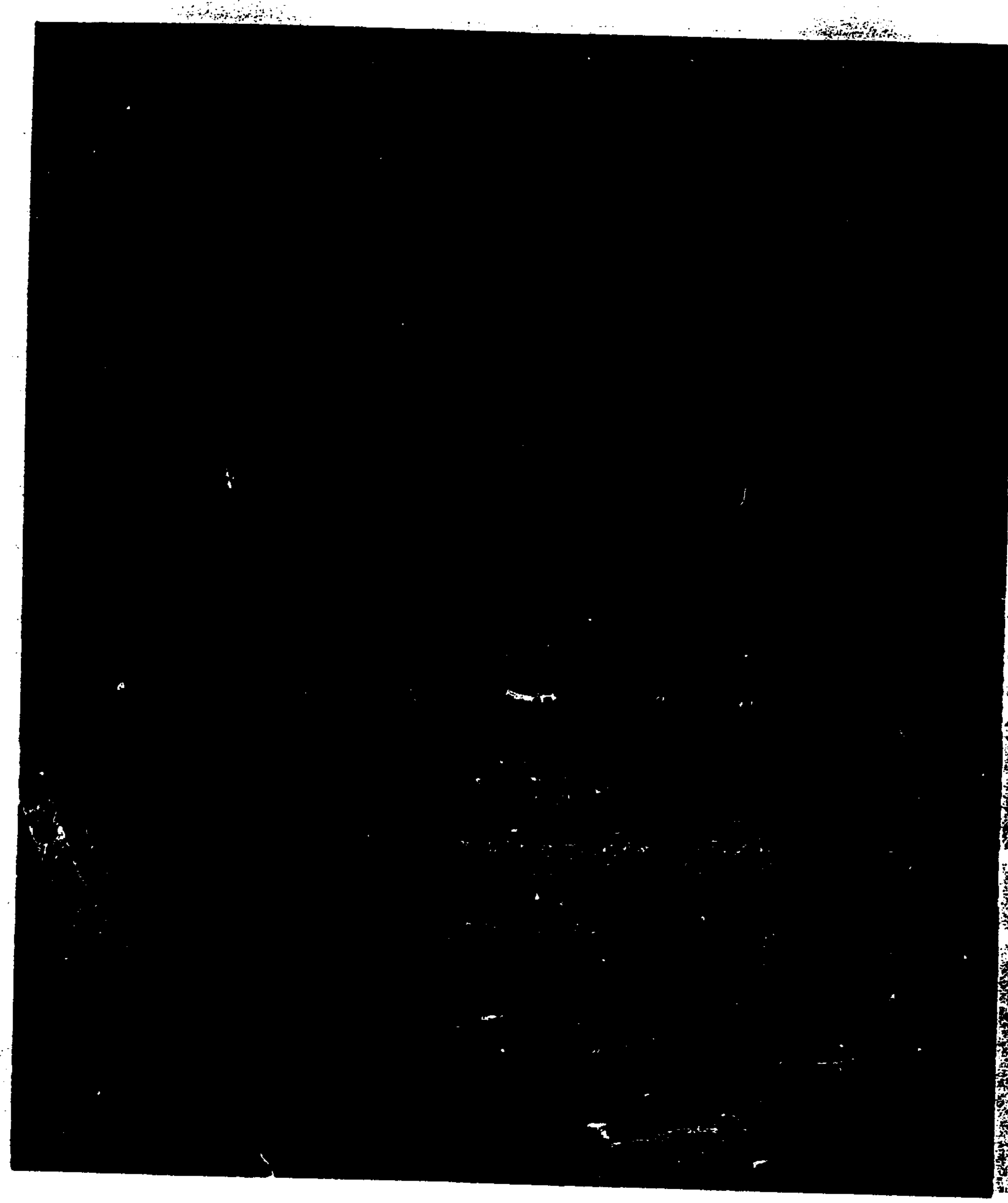
11. An attempt to directly evaluate the effects of canted oxidizer orifices on buzzing and resurging was made with injector unit X002. On this unit all of the oxidizer fans along the radial baffles were canted 4 degrees 6 minutes away from the baffles. The system still phased into a high-amplitude 480-cps buzzing mode, and the test was terminated by an observer after 2.4 seconds because of an external fire. Detailed review of the high-frequency records revealed that high-frequency components were less predominant than in previous tests. This accounted for the system not going "rough" and causing a rough combustion cutoff.

    It was reasoned that the higher frequency components which were absent from this test were at least partially attributable to compartment oscillations, and that these compartment oscillations were attenuated by a "cold" zone created by the canted fans next to the radial baffles.

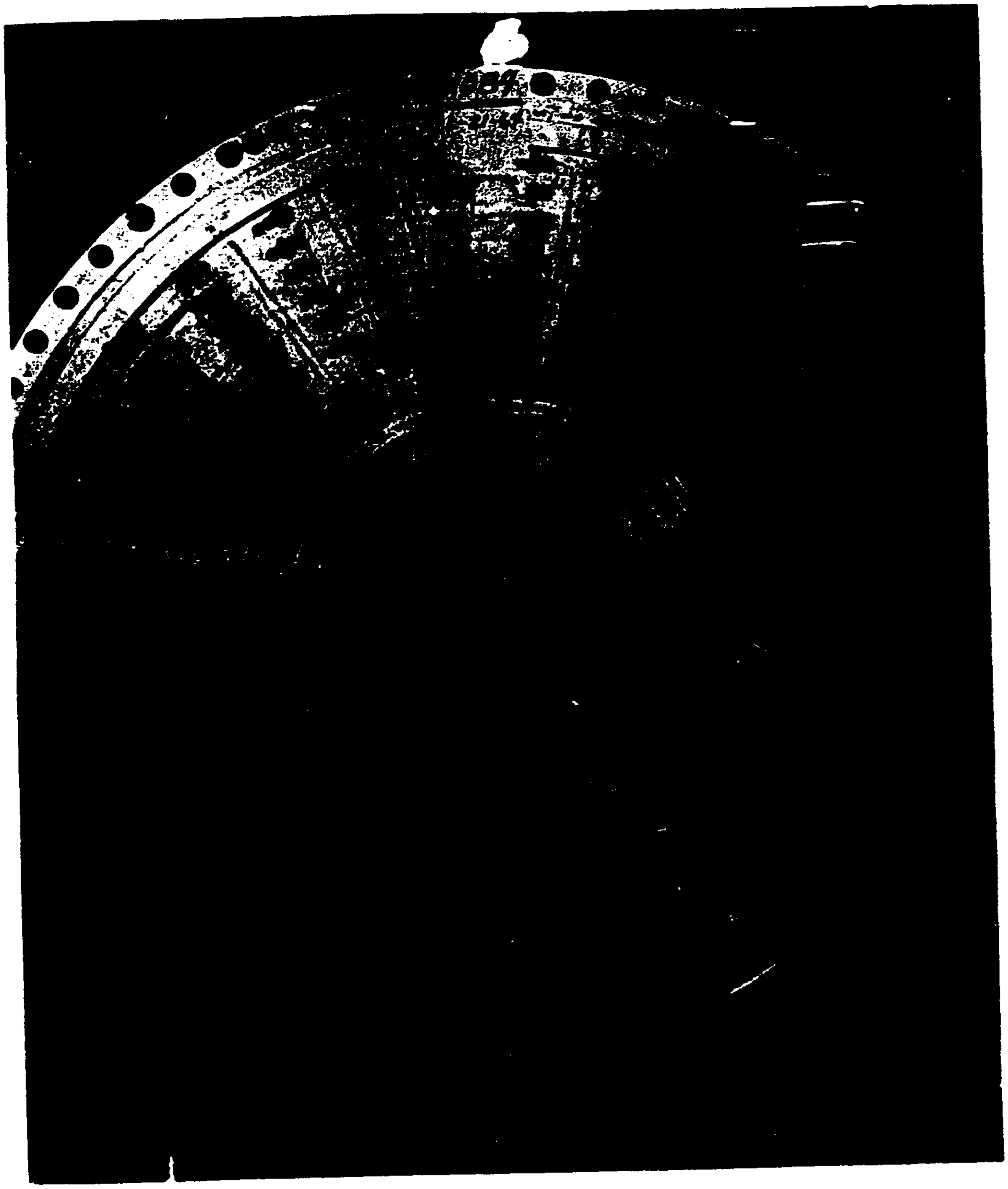
12. Five tests were conducted with injector unit 084 (Fig. 14) for stability and performance evaluation of the decreased flow in the outer fuel ring. The outer fuel ring of the injector was orificed for 70 percent of normal flow. Four bombs were detonated during this series, and the resulting disturbances damped in 10, 10, 29, and 98 milliseconds. The mode of instability appeared to be a combination of resurging and low-frequency oscillations, and a low-amplitude, 400-cps buzz was distinctly present in all tests. Equivalent engine specific impulse appeared to be about 260 seconds, which indicated an improvement over the previous unit 084 configuration.

13. Several series of tests were conducted to determine combustion chamber compatibility as well as stability and performance.

[redacted]



[redacted]



1DB41-6/21/64-C1B

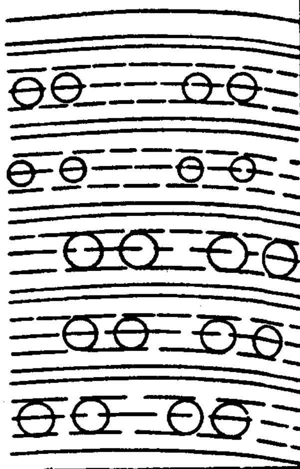
Figure 14. (Continued)

[redacted]

INJECTOR DESCRIPTION

UNIT 084, TYPE 5867M3, S/N

ORIFICE PATTERN

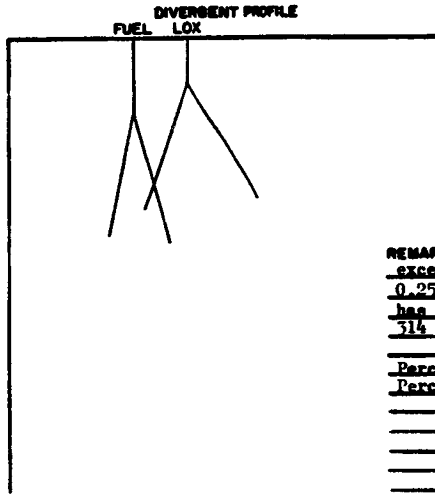


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
–59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
–57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
–55	35.626	0.281	88/96	0.428	15°	1.17	0.799	0.274
–53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.284
Except LOX orifices (0.209) next to the baffles								
–51	33.386	0.281	80/88	0.428	15°	1.17	0.799	0.274

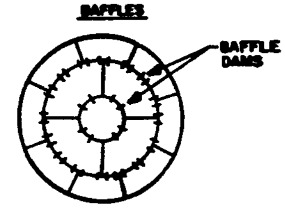
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Vel. (1500K)	55.7	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is like U/N 092, 5867J3, except the outer fuel ring is orificed with 0.257-inch tabs for ~ 70 percent flow. It has 40 baffle dams, deep LOX grooves, and 314 LOX splitters.

Percent film coolant = 3.2
Percent excess fuel on wall = 1.5

Figure 14. (Concluded)

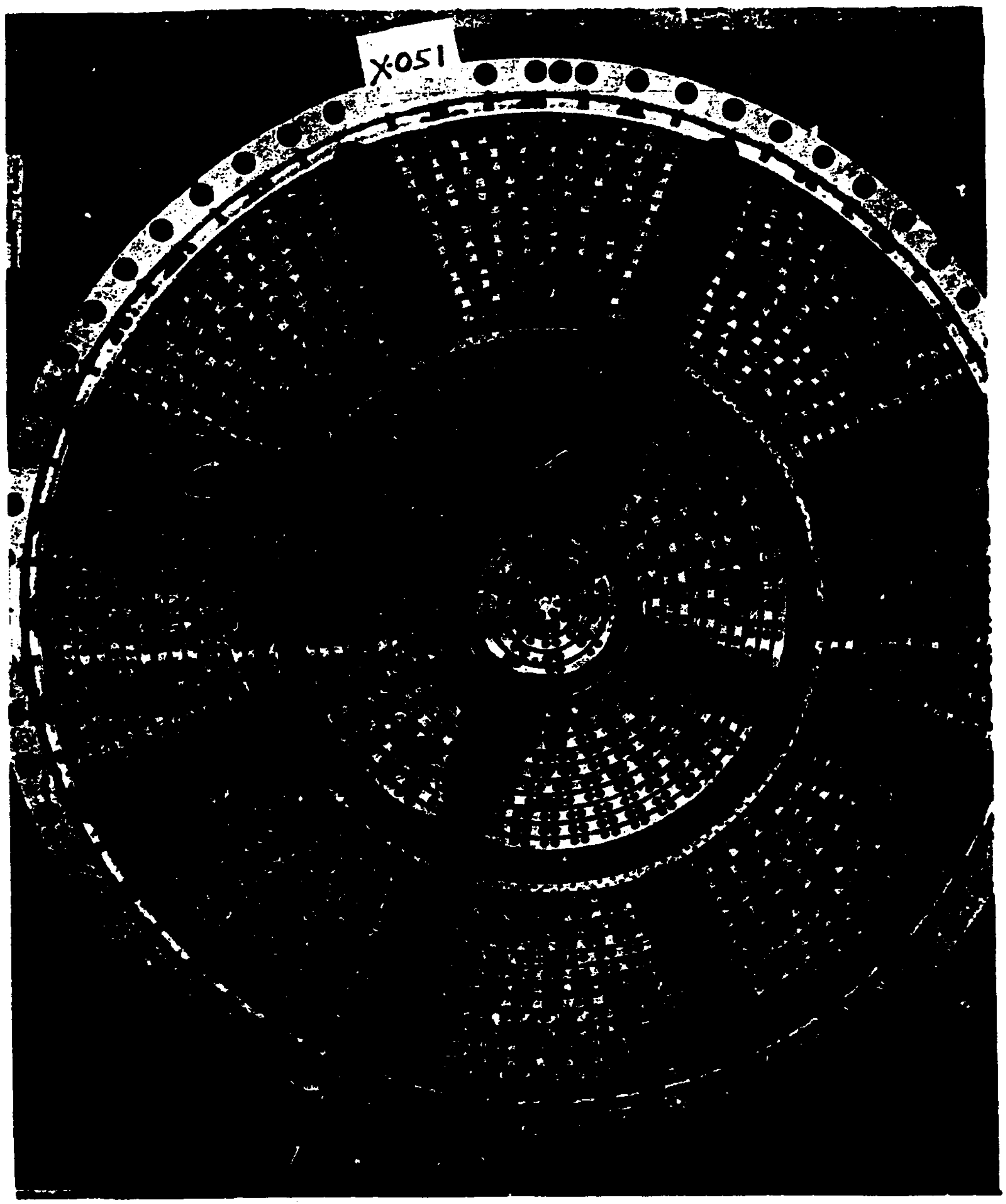
One series of tests, with injector unit F1002 (Fig. 3) was conducted to calibrate flow measurements on the 2A component stand. A series of tests, with injector unit 092 (Fig. 4) was conducted to evaluate performance, stability, and chamber compatibility. Three tests were conducted with injector unit X051 (Fig. 15). The purpose was to investigate performance, stability, and chamber compatibility. Two bomb-induced instabilities were damped in less than 19 milliseconds. A 400-cps, low-amplitude buzz was evident in chamber pressure and oxidizer parameters from 90 percent chamber pressure until the bomb detonation. However, there were only slight indications of oscillation after the bomb disturbances damped.

Several other tests were conducted to evaluate the aforementioned concepts. A complete test summary is given in Table 2 . Description sheets of injector modifications not mentioned in the text are presented in Fig. 16 through 32.

H-1 FOR F-1 PROGRAM

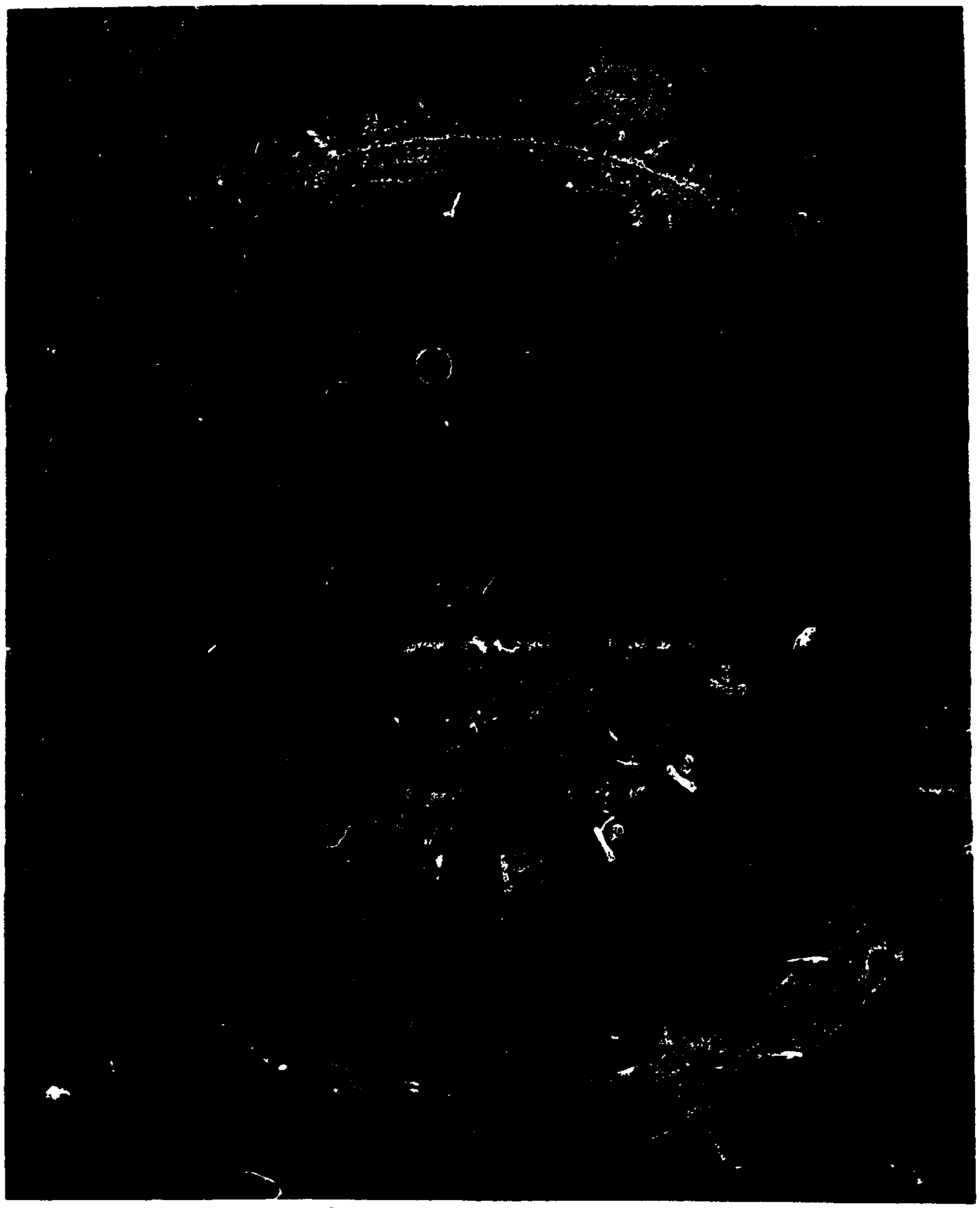
During this period the H-1 for F-1 Stability Program was completed. Nine tests on two injector units were conducted in April 1964. Two tests were conducted on injector type 5581 (Fig. 31) and seven tests were conducted on injector type 5582 (Fig. 32). A summary of the tests conducted in April is presented in Table 3.

Injector type 5581 had 114 groups of LOX and fuel orifices in the outer two rings. No film coolant was provided in the outer fuel ring. The outer LOX ring had a triplet pattern of 0.571-inch impingement. From the test results, it was concluded that a certain orifice pattern could provide long-duration testing without film coolant. Also, if the number of LOX and fuel orifice pairs in the outer periphery is increased, the c* efficiency is increased.



1DB41-5/22/64-C2A

Figure 15. Injector X051, Type 5867L3



1DB41-5/22/64-C2B

Figure 15. (Continued)

[redacted]

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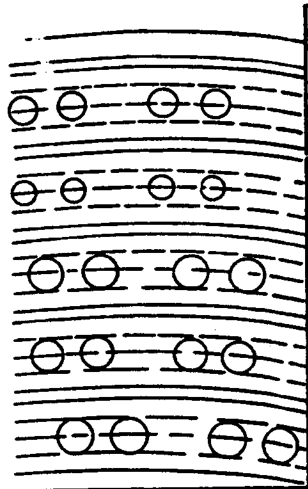
INJECTOR DESCRIPTION

UNIT X051, TYPE 586713, S/N

ORIFICE PATTERN

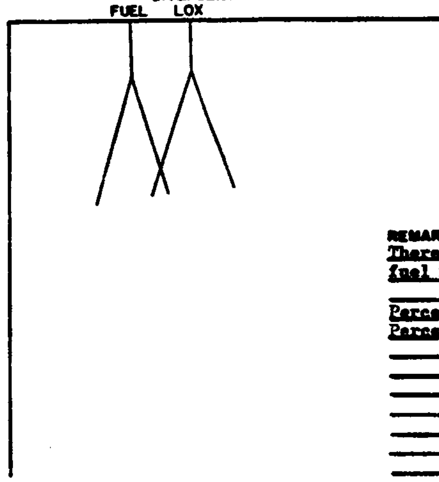


NO.	D	d	GROUP	Z	θ	Sp	Xjo	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
-55	35.626	0.281	88/96	0.428	15°	1.17	0.799	0.274
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.238
Except LOX holes (0.209) next to all baffles								
-51	33.386	0.281	80/88	0.428	15°	1.22	0.799	0.274

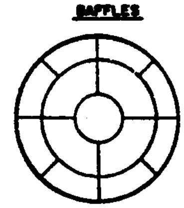
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. Vel. (1500K)	155.7	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector has deep LOX grooves. There are 314 LOX splitters and there are also fuel manifold dams (fuel port isolation tabs).

Percent film coolant = 4.6
Percent excess fuel on wall = 2.2

Figure 15. (Concluded)

[redacted]

TABLE 2

F-1 INJECTOR COMPONENT TEST SUMMARIES

Test:	106 (2A-1) 4-2-64
Injector Type:	5855SS, U/N: X002, Aot: 48.0, Aft: 85.0, Vo(1500K): 170, Vf(1500K): 56
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.209-inch diameter LOX doublets at 28 degrees 12 minutes; 0.281-inch diameter fuel doublets at 15 degrees (outer ring is 0.228-inch diameter at 20 degrees); deep LOX grooves, countersunk LOX orifices, no film or body coolants, 314 LOX splitters, four radial baffles and a can in the LOX dome cavity which seals to the injector and dome
Objective:	To determine whether complete isolation in the dome would affect the 500-cps buzz
Test Results:	No bombs were employed, but the test was cut immediately by the RCC device
Frequency Analysis:	The data were similar to test 103 except the system started buzzing, went rough, and damped three times
Test:	107-108 (2A-1) 4-3-64
Injector Type:	5862TT, U/N: 081, Aot: 49.2, Aft: 85.1, Vo(1500K): 169, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 15 degrees (0.288 inch-diameter outer ring at 20 degrees) 0.209-inch diameter LOX doublets at 20 degrees throughout; no film or body coolant orifices, 192 LOX splitters, no fuel port inserts, outer fuel ring orificed for one-half flow

[redacted]

TABLE 2
(Continued)

Objectives:	To increase performance by enlarging the remainder of the LOX orifices
Test Results:	A bomb was employed only in each test and the resulting resurging-type instabilities damped in 65 and 43 milliseconds. Performance increased nearly 2 percent by c* efficiency.
Test:	109, 110, 111 (2A-1) 4-4-64
Injector Type:	5833UU, U/N: 082, Aot: 48.0, Aft: 85.1, Vo(1500K): 170, Vf(1500K): 56
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.209-inch diameter LOX doublets at 28 degrees 12 minutes (except next to baffles where one orifice of each pair is at 20 degrees); 0.281-inch diameter fuel doublets at 15 degrees (0.228 at 20 degrees for outer ring); all film and body coolant holes plugged; 314 LOX splitters; 156 fuel ring dams
Objective:	To determine effect of fuel ring dams on 500-cps buzz
Test Results:	In three tests, four bomb disturbances damped within 7 milliseconds and performance was good.
Frequency Analysis:	There were only slight traces of 500-cps in fuel parameters shortly after the bomb disturbances.

[redacted]

TABLE 2
(Continued)

Test:	112 (2A-1) 4-6-64
Injector Type:	5863PP, U/N: X040, Aot: 51.3, Aft: 77.30, Vo(1500K): 159, Vf(1500F): 61.3
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees included angle, 0.238-inch diameter LOX doublets at 76 degrees included angle; no film or body coolant, outer fuel ring, outer LOX ring and LOX ring immediately outboard of the outer can are all plugged; hydraulic modifications are 340 LOX splitters and fuel injection tabs; percent excess fuel in the outer periphery = 7.06
Objective:	To determine if plugging the outer ring would produce stability
Test Results:	Due to extreme LOX injection area changes, LOX differential pressure was miscalculated; resulting LOX flow was only 3575 which produced 1008 P_c and 1.97 mixture ratio; no bomb was employed and there was no buzzing despite the fact that several of the plugs failed; c* efficiency was 85.4 percent
Test:	113, (2A-1) 4-7-64
Injector Type:	5864VV, U/N: X011, Aot: 49.2, Aft: 30.0, Vo(1500K): 166.1, Vf(1500K): 154.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.159-inch diameter fuel doublets at 40 degrees included angle, 0.209-inch diameter oxidizer doublets at 56 degrees 24 minutes included angle; no film or body coolant, no countersink, deep LOX grooves (0.538 inch)

[redacted]

TABLE 2
(Continued)

Objective:	Determine effect of change in fuel atomization on the 500-cps buzz
Test Results:	The test was cut by the RCC device before steady-state measurements could be made.
Frequency Analysis:	Self-initiated 500-cps buzzing was followed by steep-fronted 500-cps oscillations at high amplitudes.
Test:	114, (2A-1) 4-8-64
Injector Type:	5865WW, U/N: 075, Aot: 44.6, Aft: 84.8, Vo(1500K): 183.2, Vf(1500K): 55.9
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees (included angle) except for outer ring: 0.228-inch diameter at 40 degrees; 0.199-inch diameter oxidizer doublet at 56 degrees 24 minutes; countersunk LOX orifices, 314 LOX splitters, fuel port isolation tabs, no film or body coolants, programmed baffles
Objective:	To determine if smaller LOX orifices would eliminate 500-cps buzzing
Test Results:	No bomb was employed; c* efficiency was 90.4 at 2.53 mixture ratio and 1066 P_c.
Frequency Analysis:	500-cps buzzing was predominant throughout the test (700 psi in fuel, 50 to 200 psi in LOX and chamber)

[redacted]

[redacted]

TABLE 2

(Continued)

Test:	115, 116 (2A-1) 4-8-64, 4-9-64
Injector Type:	5866X, U/N: R007, Aot: 56.9, Aft: 37.11, Vo(1500K): 136, Vf(1500K): 128
Description:	5U baffled (3 x 3 uncooled); 0.221-inch diameter fuel doublets at 40 degrees, (outer fuel ring is 0.2055-inch diameter at 40 degrees with 0.089-inch diameter film coolant); 0.238-inch diameter oxidizer triplet (0.204-inch diameter showerhead) at 40 degrees; divergent ring over outer 6 rings, 14 LOX triplets along baffles plugged; circumferential fuel fans along baffles; percent film coolant = 7.6
Objective:	To determine if the 14 LOX triplets had any effect on stability
Test Results:	First test at 1080 P_c and 2.30 mixture ratio damped bomb in 10 milliseconds with a corrected c* efficiency of 89 percent. In the second test at 1123 P_c and 2.3 mixture ratio the bomb disturbance induced a low-amplitude instability which caused RCC.
Frequency Analysis:	The oscillations lasted for 565 milliseconds and appeared to contain frequencies of 1250 cps, 250 cps and 500 cps. Filtered records for determining phase relationships were not available.

TABLE 2
(Continued)

Test:	117, 118, 119 (2A-1) 4-9-64, 4-10-64
Injector Type:	5867TT, U/N: 081, Aot: 58.2, Aft: 85.1, Vo(1500K): 139.9, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees included angle, outer ring is 0.228-inch diameter at 40 degrees, oxidizer doublets in outer ring and next to baffles are 0.209-inch diameter at 40 degrees, the remainder are 0.242-inch diameter at 40 degrees, 192 LOX splitters, outer fuel ring orificed for one-half flow. All film and body coolants plugged, basically a modification I injector with no fuel port inserts; 4.6 percent film coolant
Objective:	To improve performance and stability by enlarging the LOX orifices in the center of the baffle compartments.
Test Results:	T/N 117: 1108 P_c, 2.13 mixture ratio, RCC, instability lasted 288 milliseconds, c* efficiency = 92.8 T/N 118: 1120 P_c, 2.26 mixture ratio, RCC, instability lasted 240 milliseconds, c* efficiency = 92.6 T/N 119: 1117 P_c, 2.38 mixture ratio, no bomb employed, c* efficiency = 94.5, baffles bent clockwise
Frequency Analysis:	The mode of instability in T/N 117 and 118 was resurging. There was no trace of 500-cps buzzing in any of the records in any of the tests.

TABLE 2
(Continued)

Test:	120 (2A-1) 4-10-64
Injector Type:	5830XX, U/N: X007A, Aot: 53.3, Aft: 66.6, Vo(1500K): 153.5, Vf(1500K): 71
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.228-inch diameter fuel doublets at 40 degrees (outer fuel ring is 0.272-inch diameter doublets at 40 degrees with 0.154-inch diameter film coolant); 0.185-inch diameter LOX triplets at 40 degrees, 32 dams in the outer fuel rings; basically a modification II injector without flame suppressors or ASME orifices in the outer two rings; 14.1 percent film coolant
Objective:	To determine the effect of removing the 32 LOX splitters on resurging
Test Results:	c* efficiency was 92.1 at 1101 P_c and 2.2. mixture ratio; bomb induced instability which lasted for 287 milliseconds and caused RCC
Frequency Analysis:	Mode of instability was resurging; 480 to 500 cps oscillations were present in LOX and fuel parameters.

[redacted]

TABLE 2
(Continued)

Test: 121, 122 (2A-1) 4-11-64

Injector Type: 5833YY, U/N: 082B, Aot: 48.0, Aft: 85.1, Vo(1500K): 170, Vf(1500K): 56.0

Description: 5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees; (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter oxidizer doublets at 56 degrees 24 minutes (orifice facing baffle is at 20 degrees half angle); no film or body coolant holes, 314 LOX splitters, 16 dams in outer circumferential baffle, 156 fuel ring groove dams, baffle land gap sealed, 4.6 percent film coolant

Objective: To determine the effect of the baffle dams on 500-cps buzz

Test Results: c* efficiency was 93 percent for the two tests at about 1000 P_c. Bomb disturbances damped in 8 and 6 milliseconds

Frequency Analysis: Very low-amplitude 500-cps oscillations were discernible in fuel parameters throughout both tests. This was also confirmed by a power spectral analysis.

[redacted]

TABLE 2

(Continued)

Test:	123, 124, 125 (2A-1) 4-13-64, 4-13-64, 4-14-64
Injector Type:	5833YY, U/N: 082B, Aot: 48.0, Aft: 85.1, Vo(1500K): 170, Vf(1500K): 56
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees; (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter oxidizer doublets at 56 degrees 24 minutes (orifice facing baffle is at 20 degrees half angle); no film or body coolant holes, 314 LOX splitters, 156 fuel ring dams, 16 dams in outer circumferential baffle, baffle-land gap sealed, 4.6 percent film coolant; low differential pressure dome E005 employed
Objective:	To determine the effects of the dome on buzz, bomb stability, and LOX differential pressure
Test Results:	Test 123 was run at 836 P_c and 2.25 mixture ratio without a bomb, and programmed duration was achieved without any apparent hardware damage; test 124 was run at 1107 P_c and 2.63 mixture ratio without a bomb and again the system went for programmed duration without damage; two bombs were employed in test 125 with 1114 P_c and 2.33 mixture ratio; an RCC was experienced; the dome had about 86 psi less pressure drop at 4000 lb/sec.
Frequency Analysis:	Test 123 exhibited a low-amplitude, out-of-phase 400-cps buzz in all parameters throughout the entire mainstage portion of the run. In test 124 there were no clear frequencies discernible in any parameter. Test 125, however, exhibited some low-amplitude, intermittent buzzing in fuel parameters after the bomb disturbances. The bomb disturbances were damped in 28 and 8 milliseconds which, coupled with ignition start, was enough for an RCC based on accumulated count.

TABLE 2

(Continued)

Test: 126, 127 (2A-1) 4-15-64, 4-16-64

Injector Type: 5855-ZZ, U/N: X002, Aot: 48.0, Aft: 85.0, Vo(1500K): 170, Vf(1500K): 56

Description: 5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees, (outer ring is 0.228-inch diameter at 40 degrees). 0.209-inch diameter oxidizer doublets at 56 degrees 24 minutes, no film or body coolant holes, deep LOX grooves, 314 LOX splitters, 8 dams in outer circumferential baffle; 4.6 percent film coolant

Objective: To determine the effect of the baffle dams on the 500-cps buzzing

Test Results: No bombs were employed, but both tests were cut by the RCC device after less than 1 second of mainstage. Test 126 was too short for steady-state data, but some measurements from test 127 indicated that c* efficiency was about 93 percent at 1112 P_c and 2.51 mixture ratio.

Frequency Analysis: Shortly after 90 percent P_c in both tests, 500-cps buzzing commenced, which was followed by a general roughness throughout the system. This roughness appeared to start in the fuel injection parameters and damped out prior to P_c decay and the return of buzzing.

[redacted]

TABLE 2
(Continued)

Test:	128, 129 (2A-1) 4-17-64
Injector Type:	5833D3, U/N: 082B, Aot: 48.0, Aft: 85.1 Vo(1500K): 170, Vf(1500K): 56
Description:	5U baffled (13 x 3 wide-base fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter oxidizer doublets at 56 degrees 24 minutes (orifice facing baffle is at 20 degrees half angle); no film or body coolant holes, 314 LOX splitters, 164 fuel ring dams, 16 dams in outer circumferential baffle, 8 dams in inner baffle can; 4.6 percent film coolant, low differential pressure dome employed
Objective:	To determine the effects of the inner can dams on 500-cps buzz.
Test Results:	Two tests were run for programmed duration. Two bombs damped in 5 and 10 milliseconds, and c* efficiencies were 94.6 and 94.1 percent.
Frequency Analysis:	There were no clear 500-cps oscillations of significant duration at any time or in any parameter of either test.

[redacted]

TABLE 2

(Continued)

Test:	130, 131 (2.-1) 4-18-64
Injector Type:	5867A3, U/N: 081, Aot: 58.8, Aft: 85.1, Vo(1500K): 139.9, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees) oxidizer doublets in outer ring and next to baffle are 0.209 at 40 degrees, the remainder are 0.242 inch-diameters at 40 degrees; 314 LOX splitters, no film or body coolant holes, no fuel port inserts, outer fuel ring orificed for one-half flow
Objective:	To determine the effect of the splitters on the resurging mode of instability
Test Results:	c* efficiencies for the two tests were 95.1 and 94.4 and the bomb disturbances damped in 11, 10, and 11 milliseconds.
Frequency Analysis:	All three bomb disturbances damped without resurging and without the appearance of 500-cps oscillations except for one fuel inlet measurement, which indicated 4 cycles.

TABLE 2
(Continued)

Test:	132, 133 (2A-1) 4-21-64
Injector Type:	5867A3, U/N: 081, Aot: 58.8, Aft: 85.1, Vo(1500K): 139.9, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter oxidizer doublets at 40 degrees in outer ring and next to baffles, the remainder are 0.242-inch diameter at 40 degrees; 314 LOX splitters, no film or body coolant holes, no dome baffles, no fuel port inserts, outer fuel ring orificed for one-half flow
Objective:	To determine reproducibility of the results of tests 130 and 131
Test Results:	At near nominal conditions, c* efficiency was 93.5 percent and three bomb disturbances damped within 13 milliseconds.

TABLE 2

(Continued)

Tests:	134, 135 (2A-1) 4-22-64, 4-23-64
Injector Type:	5855E3, U/N: X002, Aot: 48.0, Aft: 85.0, Vo(1500K): 170, Vf(1500K): 56
Description:	5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees, (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter LOX doublets at 56 degrees 24 minutes, 164 fuel ring dams, 314 LOX splitters, 8 dams in outer circumferential baffle, no film or body coolant orifices, 2.2 percent film coolant
Objective:	Investigation of the baffle dams on buzzing
Test Results:	In both tests the system self-triggered and was cut off by the RCC device before steady-state data could be obtained.
Frequency Analysis:	For the first 100 milliseconds, the instabilities on both tests consisted of gradually diverging 500-cps oscillations. Bursts of 6000-cps oscillations at high amplitude occurred and then appeared at regular times corresponding to 500-cps oscillations. In test 134, these high frequencies damped out, but reappeared again after 500-cps buzzing reappeared and diverged. This did not occur in test 135.

TABLE 2

(Continued)

Test:	136, 137, 138 (2A-1) 4-24-64
Injector Type:	5867A3, U/N; 081, identical to injector 081 on tests 132 and 133; tube-wall thrust chamber 20-4 used
Objective:	To investigate a potential tube burning problem in a cooled thrust chamber
Test Results:	Three tests conducted at nominal conditions for durations of 1.69, 1.76 and 2.65 seconds. There was evidence of tubes overheating on all tests and in the third, two tube splits appeared. However, the percentage bypass may have been closer to 70 percent than the nominal 32 percent.

TABLE 2

(Continued)

Test:	139 (2A-1) 4-27-64
Injector Type:	5855F3, U/N: X002, Aot: 48.0, Aft: 85.0, Vo(1500K): 170, Vf(1500K): 56
Description:	5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter LOX doublets at 56 degrees 24 minutes, 164 fuel ring dams, 314 LOX splitters, 16 dams in outer circumferential baffle, (8 more than previous configurations), no film or body coolant orifices, 2.2 percent film coolant.
Objective:	Investigation of the effect of the baffle dams on buzzing
Test Results:	System self-triggered and was cut by the RCC before steady-state data could be obtained.
Frequency Analysis:	Mode consisted of 500-cps buzzing with regular bursts of 6000 cps appearing in fuel parameter bursts.

TABLE 2

(Continued)

Test:	140 through 151 (2A-1) 4-28-64 through 5-1-64
Injector Type:	5867A3, U/N: 081, Aot: 58.8, Aft: 85.1, Vo(1500K): 140, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees); 0.209-inch diameter oxidizer doublets at 40 degrees in outer ring and next to baffles, the remainder are 0.242-inch diameters at 40 degrees; 314 LOX splitters, no film or body coolant holes, no dome baffles or fuel port inserts, outer fuel ring orificed for one-half flow
Objective:	Verification of performance data on long-duration runs and investigation of a potential tube burning problem
Test Results:	Tests 140 through 143 were conducted with the low differential pressure dome and Inconel-X chamber 20-4 for durations of 2.6, 4.5, 6.6, and 8.7 seconds. The chamber showed signs of overheating, and there were 32 transverse tube cracks and 3 tube failures. Failure to install bypass plugs resulted in about 70 percent fuel bypass; c* efficiency averaged 92.0 for the four runs. Tests 144 through 151 were conducted with the low differential pressure dome and nickel chamber 20-14 for durations of 6.8, 8.0, 10.7, 10.7, 10.6, 10.6, 10.6 and 10.6 seconds. There was some burning of the injector face between orifice pairs and some overheating and cracking of chamber tubes. However, there were no major tube failures of any type, and c* efficiency averaged 92.3 percent for the eight tests. In test 150 a self trigger occurred and the system damped in 17 milliseconds without resurging.

TABLE 2
(Continued)

Test:	152 (2A-1) 5-2-64
Injector Type:	5871F3, U/N: X002. This injector is identical to 5855F3 used in test 139 except all LOX orifices not in the outer ring or next to a baffle were enlarged to 0.242 inches, thereby making Aot: 58.8 and Vo(1500X): 139.
Objectives:	To determine the effect of change in orifice size on 500-cps buzzing
Test Results:	System self-triggered and was cut by the RCC before steady-state data could be obtained.
Frequency Analysis:	The mode was 500-cps buzzing, later accompanied by 6000-cps in the fuel system. The buzzing and 6000-cps ringing appeared to be more steady than any of the previous tests of this injector.

TABLE 2

(Continued)

Test:	153 (2A-1) 5-2-64
Injector Type:	5865D3, U/N: 075, Aot: 44.6, Aft: 84.8, Vo(1500K): 183.2, Vf(1500K): 55.9
Description:	5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.199-inch diameter LOX doublets at 56 degrees 24 minutes, 314 LOX splitters, 164 fuel ring dams, 24 dams in outer circumferential baffles, 8 dams in inner circumferential baffle, no film or body coolant holes, LOX orifices countersunk; 4.6 percent film coolant
Objective:	To investigate the effect of the baffle dams on 500-cps buzz
Test Results:	System self-triggered and was cut off by the RCC before steady-state data could be obtained.
Frequency Analysis:	The mode was 500-cps buzzing which remained clear and distinct until P_c decay. There was a noticeable lack of higher frequency content when compared to previous results on injector U/N X002.

TABLE 2
(Continued)

Tests:	154 through 157 (2A-1) 5-4-64 (2) 5-5-64 (2)
Injector Type:	5873A3, U/N 081, Aot: 58.8, Aft: 84.9, Vo(1500K): 139.9, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled); 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees); 0.209-inch diameter oxidizer doublets at 40 degrees in outer ring and next to baffles, the remainder are 0.242-inch diameter at 40 degrees; 314 LOX splitters, no film or body coolant holes, no dome baffles or fuel port inserts, outer fuel ring orifices for one-half flow, 32 fuel orifices in outer ring swaged to improve formation of fuel fan.
Objective:	Further investigation of damping characteristics of this injector
Test Results:	All tests were conducted at near nominal conditions with dome E005. Tests 154 and 155 in chamber 1308 damped bomb disturbances in 250 and 21 milliseconds. Tests 156 and 157 in chamber 1206 damped bomb disturbances in 8, 8, and 10 milliseconds (two bombs in T/N 157); c* efficiency ranged from 92.1 to 94.1 percent.
Frequency Analysis:	In test 154, the mode of instability was moderate to low-amplitude resurging. As is usually the case, there was nothing immediately obvious in the data which indicated why 154 continued to resurge while the other three tests did not.

TABLE 2

(Continued)

Tests:	158, 159 (2A-1) 5-6-64
Injector Type:	5874J3, U/N 092, Aot: 58.8, Aft: 31.1, Vo(1500K): 138.9, Vf(1500K): 152.4
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.159-inch diameter fuel doublets at 40 degrees; 0.209-inch diameter LOX doublets at 40 degrees in outer ring and next to baffles, the remainder are 0.242-inch diameter at 40 degrees; deep LOX grooves, 314 LOX splitters, rotated and programmed baffles, 40 baffle dams (32 + 8), outer fuel ring orificed for one-half flow; 3.28 percent film coolant
Objective:	To evaluate damping characteristics of an 081-type LOX system coupled with small fuel orifices.
Test Results:	The first test was a successful check run with c* efficiency better than 95 percent. The second test was cut by an observer due to an external fire in the chamber area. The bomb thermally detonated during P_c decay. During the second test, all baffles were severely eroded.
Frequency Analysis:	The instability lasted 140 milliseconds. Amplitudes were low and there were no distinct frequencies present. There did appear to be some indications of resurging.

TABLE 2

(Continued)

Tests:	160 through 172 (2A-1) 5-7-64 through 5-9-64
Injector Type:	5873A3, U/N 081, identical to configuration for tests 154 through 157; low-differential-pressure dome E005 and tube wall chamber 20-14 employed
Objective:	Further investigation of damping and tube burning
Test Results:	No bombs were employed in the first six runs; c* efficiency averaged about 92.4 percent. In the other 7 tests, 10 bomb disturbances damped in an average time of 16.7 milliseconds. Seven of the disturbances were single cycle dampers (less than 15 milliseconds); the other three were damped in 35, 20, and 30 milliseconds. There were no serious problems with the tube wall chamber.

TABLE 2

(Continued)

Test:	173 (2A-1) 5-9-64
Injector Type:	5875A3, U/N 081, identical configuration as used on tests 160 through 172 except dome 009R and solid-wall 1107 were employed
Objective:	To determine if low-differential-pressure dome had a significant effect on the stability of the system
Test Results:	At near nominal conditions a single bomb disturbance damped in 9 milli-seconds.

[redacted]

TABLE 2
(Continued)

Tests:	174 through 186 (2A-1) 5-13-64 through 5-16-64
Injector Type:	5867J3, U/N: 092, Aot: 58.8, Aft: 85.1, Vo(1500K): 138.9, Vf(1500K): 55.6
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.209-inch diameter oxidizer doublets at 40 degrees in outer LOX ring and next to all baffles, the remainder are 0.242-inch diameter at 40 degrees; deep LOX grooves, 314 LOX splitters, rotated and programmed baffles, 40 baffle dams (32 + 8), outer fuel ring orificed for one-half flow, 4.6 percent film coolant, no film or body coolant holes, fuel port isolation tabs
Objective:	Investigation of stability, performance and burning characteristics of U/N 081 type injector
Test Results:	The first four tests (174-177) employed solid wall chamber 1204 and dome E005 and damped a total of five bomb disturbances in 35, 25, 96, 60, and 153 milliseconds. The mode of instability was resurging intermixed with 400 to 450 cps oscillations; c* efficiency averaged 90.4 percent. Tests 178-180 were conducted with an Inconel-X tube wall thrust chamber (20-4) and dome E005. In test durations of 4.8, 10.6, and 10.3 seconds there were no serious tube burning problems, and c* efficiency averaged 91.8 percent.

[redacted]

TABLE 2

(Continued)

Tests 181-186 were conducted with the same hardware, but eight bombs were employed to evaluate damping characteristics in a tube-wall chamber as compared to a solid-wall. The average time to damp was 42 milliseconds, with a maximum and minimum of 13 and 113 milliseconds. The mode was similar to that of the solid-wall tests, and c* efficiency averaged about 91 percent. There was no serious damage until the final test in which some tube splitting and collapsing took place and an RCC was incurred. It was also observed after the test that eight LOX splitters in the outer ring were broken and several bypass plugs were missing from the chamber.

TABLE 2

(Continued)

Test:	187 (2A-1) 5-18-64
Injector Type:	5876F3, U/N: X002, Aot: 58.8, Aft: 85.1, Vo(1500K): 138.9, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.242-inch diameter LOX doublets at 56 degrees 24 minutes except next to baffles or in outer ring which are 0.209-inch diameter at 56 degrees 24 minutes; the circle of LOX doublets just inside the inner can has been modified to an impingement angle of 40 degrees; 164 fuel ring dams, 314 LOX splitters, 24 dams in outer circumferential baffle, no film or body coolant orifices, 2.3 percent film coolant
Objective:	Investigation of the effect of canted LOX fans on 500-cps buzzing
Test Results:	In a single test the system phased into high-amplitude, 500-cps oscillations and the test was cut off by an observer after 2.4 seconds because of an external fire. The inner can of the injector and the body coolant flat were eroded. A P_c boss blew out, causing the fire. The c* efficiency was 92.6 percent.
Frequency Analysis:	Oscillations consisted of 480-cps oscillations and a distinct lack of any other high-frequency components. The 5800-cps oscillations were discernible, but at a very low amplitude.

TABLE 2

(Continued)

Tests:	188-190 (2A-1) 5-19-64 (2) 5-20-64
Injector Type:	5869R, U/N: X035, Aot: 41.9, Aft: 86.20, Vo(1500K): 195.0, Vf(1500K): 55.0
Description:	5U baffles (3-compartment, uncooled), 0.281-inch diameter fuel doublets at 30 degrees except outer ring which are 0.228-inch diameter at 40 degrees, 0.159-inch diameter LOX triplets at 40 degrees; 38 triplets next to baffle surfaces plugged, no film or body coolant, 4.4 percent film coolant
Objective:	Investigation of fuel buffered baffle concept on stability
Test Results:	Three bomb disturbances damped in 12 milliseconds or less at P_c's from 1027 to 1095. There was no apparent hardware damage, and c* efficiency was about 88.1 percent.

TABLE 2
(Continued)

Test:	191 (2A-1) 5-20-64
Injector Type:	5877D3, U/N: X011, Aot: 50.6, Aft: 85.1, Vo(1500K): 161.5, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.221-inch diameter LOX doublets at 56 degrees 24 minutes except those orifices facing radial baffle surfaces, which are 20 degrees half-angle; LOX orifices either side of both circumferential baffles are 0.141-inch diameter at 40 degrees included angle; 32 baffle dams, 164 fuel ring groove dams, and 314 LOX splitters; no film or body coolant holes, 4.61 percent film coolant
Objective:	The injector is a combination of the U/N 082 and fuel buffered baffle concepts
Test Results:	The system phased into 500-cps oscillations and was cut off by the RCC after 1.15 seconds of duration.
Frequency Analysis:	The system phased into 500-cps buzzing for the entire duration of the run. A self trigger occurred which induced higher frequency components. Although this disturbance damped in slightly less than 40 milliseconds, an RCC was incurred.

TABLE 2

(Continued)

Tests:	192, 193 (2A-1) 5-21-64
Injector Type:	5833K3, U/N 082B, Aot: 49.2, Aft: 85.1, Vo(1500K): 166.0, Vf(1500K): 56.0
Description:	5U baffled (13 x 3 wide-base, fuel-cooled), 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees) 0.209-inch diameter oxidizer doublets at 56 degrees 24 minutes (orifice facing baffle is 20 degrees half angle); no film or body coolant holes, 314 LOX splitters, 164 fuel ring dams, 16 dams in outer circumferential baffle, 8 dams in inner baffle, 2.3 percent film coolant, outer fuel ring orificed for one-half flow
Objective:	Further investigation of the 500-cps buzzing
Test Results:	In the first run, the bomb disturbance took 110 milliseconds to damp and an RCC was incurred. In the second test with a different chamber at nearly the same conditions, the bomb disturbance damped in 6 milliseconds. The average c* efficiency was 93.3 percent, and in both tests the solid-wall chamber was severely burned.
Frequency Analysis:	There was no 500-cps buzzing discernible, and the instability was sustained by a low-amplitude, low-frequency, rather obscure resurging mode.

TABLE 2

(Continued)

Test:	194 through 197 (2A-1) 5-25-64 (2) 5-26-64 (2)
Injector Type:	5828V, U/N: F1002, Aot: 53.3, Aft: 62.3, Vo(1500K): 153.5, Vf(1500K): 75.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.228-inch diameter fuel doublets at 40 degrees, 0.185-inch diameter LOX triplets at 40 degrees ASME orifices in all but outer ring, hydraulic modification II,0.1285 film and 0.076 body coolant orifices.
Objective:	Performance comparison of engine and component stands
Test Results:	No bombs were employed. At near nominal conditions, c* efficiency averaged about 92.4 percent, as compared to about 91 percent on comparable engine tests.

[redacted]

TABLE 2

(Continued)

Test:	198 through 200 (2A-1) 5-28-64
Injector Type:	5867L3, U/N: X051, Aot: 58.8, Aft: 85.1, Vo(1500K): 138.9, Vf(1500K): 55.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 30 degrees (outer ring is 0.228-inch diameter at 40 degrees), 0.242-inch diameter LOX doublets at 40 degrees (outer LOX ring is 0.209-inch diameter at 40 degrees, LOX holes next to baffles are 0.209-inch diameter at 40 degrees), fuel manifold dams, fuel port isolation tabs, 314 LOX splitters, deep LOX grooves, outer fuel ring orificed for one-half flow, no film or body coolant holes; 4.6 percent film coolant
Objective:	Investigation of performance, stability and burning characteristics of U/N 081 type injectors
Test Results:	The first test resulted in a fail-safe cutoff because the main LOX valve failed to reach full open. At 1084 P_c and 2.63 mixture ratio in the second test, the system damped a bomb disturbance in 10 milliseconds. In test No. 200 at 1113 P_c and 2.31 mixture ratio the system resurged once and damped in 19 milliseconds.
Frequency Analysis:	In test No. 200, a 400-cps, low-amplitude buzz was evident in P_c and LOX parameters from shortly after 90 percent P_c until the bomb detonation. There were only slight indications of the oscillation from the time at which the bomb damped until cutoff.

[redacted]

[redacted]

TABLE 2

(Continued)

Tests:	201 through 205 (2A-1) 6-19-64 through 6-20-64
Injector Type:	5828V, U/N: F1002, Aot: 53.3, Aft: 62.3, Vo(1500K): 153.5, Vf(1500K): 75.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.228-inch diameter fuel doublets at 40 degrees, 0.185-inch diameter LOX triplets at 40 degrees with ASME orifices in all but outer ring, hydraulic modification II, 0.1285-inch diameter film and 0.076-inch diameter body coolant orifices
Objective:	Calibration of component flow instrumentation
Test Results:	Five 10-second tests were successfully conducted with tube-wall thrust chamber 20-14 at P_c's ranging from 1004 to 1122. The average equivalent engine specific impulse was 260.4 seconds. There was no significant change in the condition of the hardware.

[redacted]

TABLE 2
(Continued)

Test:	206 (2A-1) 6-22-64
Injector Type:	5828V, U/N: F1002, Aot: 53.3, Aft: 62.3, Vo(1500K): 153.5, Vf(1500K): 75.7
Description:	5U baffled (13 x 3 wide-base, fuel-cooled) 0.228-inch diameter fuel doublets at 40 degrees, 0.185-inch diameter LOX triplets at 40 degrees with ASME orifices in all but the outer ring, hydraulic modification II, 0.1285-inch diameter film and 0.076-inch diameter body coolant orifices
Objective:	Calibration of component flow instrumentation
Test Results:	Single 10.1-second tube-wall test conducted with similar results as tests 200-205. Stand flowmeter calibrations were still in question and there was no apparent change in hardware conditions.

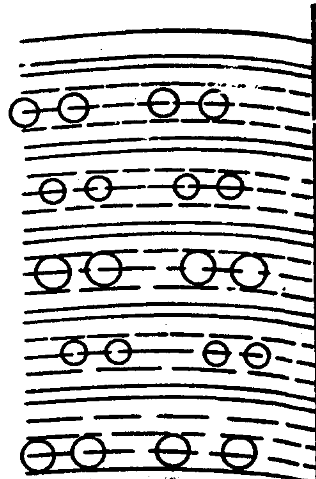
TABLE 2
(Concluded)

Test:	207-211 (2A-1) 6-23-64
Injector Type:	5867M3, U/N 084, Aot: 58.8, Aft: 85.1, Vo(1500K): 138.9, Vf(1500K): 55.7
Description:	Modified 5U baffled (13 x 3 wide-base, fuel-cooled) 0.281-inch diameter fuel doublets at 40 degrees, (outer ring consists of 0.228-inch diameter doublets at 40 degrees); 0.209-inch diameter LOX doublets next to baffles and in outer ring at 40 degrees, 0.242-inch diameter at 40 degrees elsewhere; outer fuel ring orificed for 70 percent flow, 40 baffle dams, deep LOX grooves, fuel port isolation tabs and 314 LOX splitters, 3.2 percent wall coolant, no film or body coolant orifices, rotated baffles
Objective:	Stability and compatibility evaluation of 092-type injector with 70 percent fuel flow in the outer ring
Test Results:	Five tests were conducted in the tube-wall thrust chamber 20-14 and programmed 10 seconds duration was attained in all but the last. Four bombs detonated and the resulting disturbances damped in 10, 10, 29, and 98 milliseconds. There was no significant change in the hardware conditions.
Frequency Analysis:	The instability appeared to be sustained by resurging coupled with low-amplitude, middle-frequency (200 to 500 cps) oscillations. In all tests a 400-cps, out-of-phase buzz was present at a peak-to-peak amplitude of about 200 psi in LOX injection parameters.

INJECTOR DESCRIPTION

UNIT 075, TYPE 5865D3, S/N

ORIFICE PATTERN

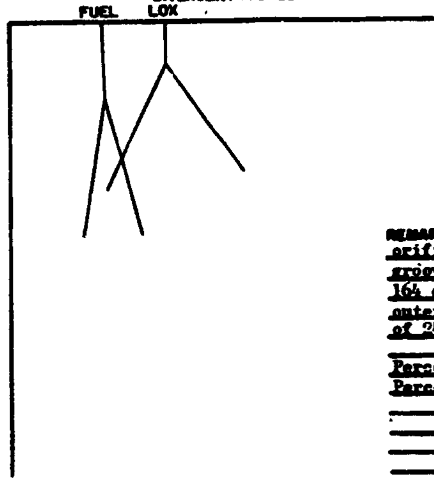


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.199	96/104	0.374	28.2	1.11	0.349	0.163
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.506	0.199	88/96	0.374	28.2	1.13	0.349	0.163
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

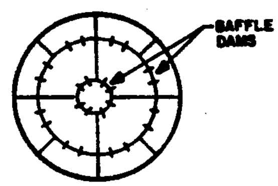
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	84.8	44.6
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY(1500K)	55.9	183.2

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Basic 5U orifice pattern with LOX orifices countersunk; 15% more fuel ring grooves have been added making a total of 164 dams, and 8 dams have been added to the outer circumferential baffle, making a total of 24.

Percent film coolant = 4.6

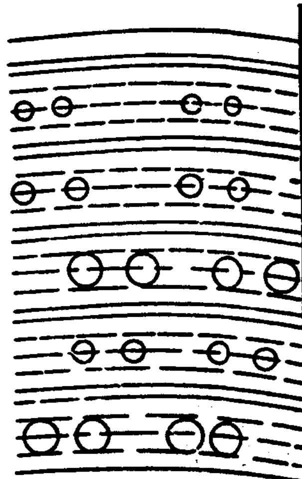
Percent excess fuel on wall = 2.2

Figure 16. Injector Unit 075, Type 5865D3

INJECTOR DESCRIPTION

UNIT 081, TYPE 5867 TT, S/N

ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjl
WALL	39.188							
	37.961	—	—	—	—	—	—	—
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.254
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
-55	35.6-6	0.281	88/96	0.428	15°	1.17	0.744	0.254
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.284
Except holes (0.209) along the baffles								
-51	33.386	0.281	80/88	0.428	15°	1.22	0.744	0.254

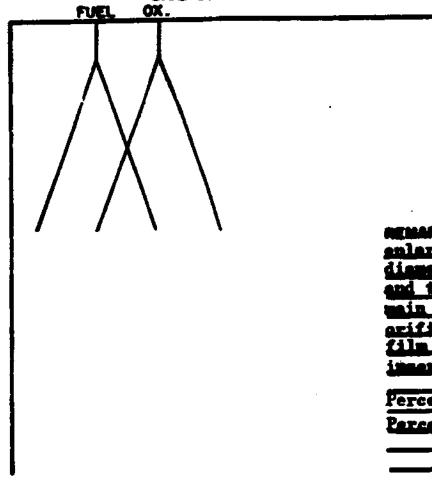
PATTERN, GENERAL

	FUEL	OXID.
ORIFICE AREA	85.118	58.8
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (1500)	55.7	139.9

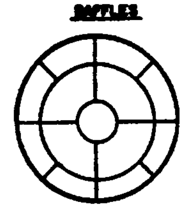
BAFFLE DESIGN

NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Injector modification consisted of enlarging all LOX orifices to 0.242-inch diameter except those in the outer LOX ring and those along the radials and the cans remain at 0.209. The outer fuel ring remains orificed for 50 percent flow; all body and film coolant remain plugged; no fuel port inserts.

Percent excess fuel on wall = 2.22

Percent film coolant = 4.6

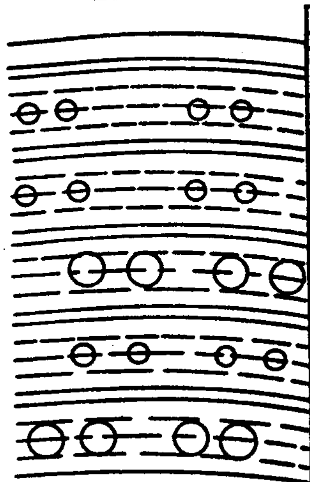
Figure 17. Injector Unit 081, Type 5867TT

[redacted]

INJECTOR DESCRIPTION

UNIT 081, TYPE 5867 A3, S/N

ORIFICE PATTERN

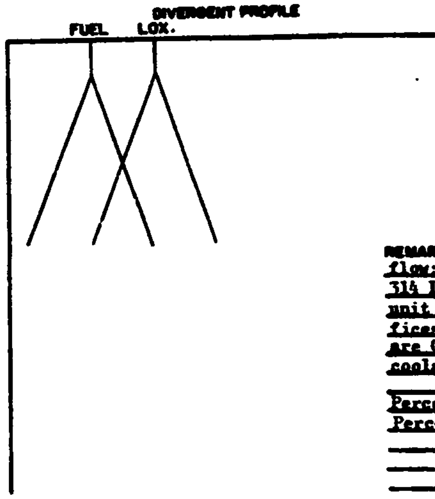


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
	37.961							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	[illegible]
-55	35.626	0.291	88/96	0.428	15°	1.17	0.744	0.254
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.284
Except holes (0.209) along the baffles								
-51	33.386	0.281	80/88	0.428	15°	1.22	0.744	0.254

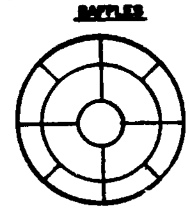
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.118	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (1500K)	55.7	139.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Outer fuel ring orificed for 50 percent flow; injector modification consisted of adding 314 LOX splitters in a pattern like that of unit 082; baffles are programmed and LOX orifices next to baffles and in the outer LOX ring are 0.209; the rest are 0.242; body and film coolants remain plugged; no fuel port inserts

Percent excess fuel on wall = 2.22

Percent film coolant = 4.6

Figure 18. Injector Unit 081, Type 5867A3

[redacted]

[redacted]

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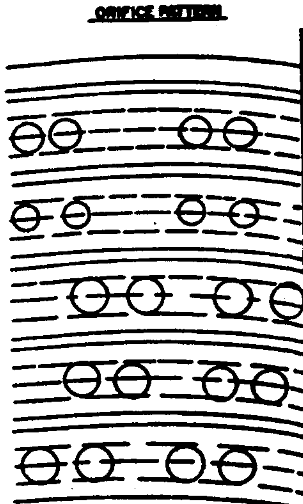
INJECTOR DESCRIPTION

UNIT 081, TYPE 5873A3, S/N

ORIFICE PATTERN



NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjl
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
Except for 16 doublets which are as indicated below								
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
-55	35.626	0.281	88/96	0.428	15°	1.17	0.744	0.254
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.284
-51	33.386	0.281	80/88	0.428	15°	1.22	0.744	0.254

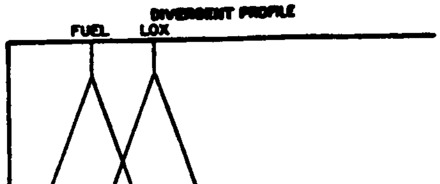
PATTERN GENERAL

	FUEL	OXID.
ORIFICE AREA	84.9	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	CU	CU
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (1500)	55.8	138.9

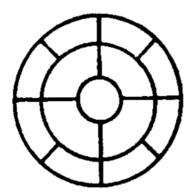
BAFFLE DESIGN

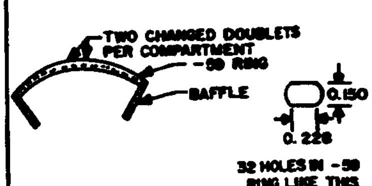
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 inches

DIVERGENT PROFILE



BAFFLES





REMARKS: The injector is the same as Unit 081, 5867A3, except for the 16 fuel doublets in the outer ring which were changed as shown at left.

Percent film coolant = 4.6

Percent excess film on wall = 2.2

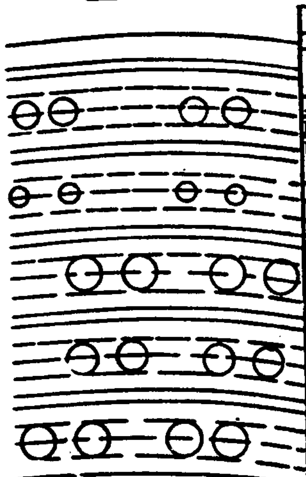
Figure 19. Injector Unit 081, Type 5873A3

[redacted]

INJECTOR DESCRIPTION

UNIT 081, TYPE 5875A3, S/N ________

ORIFICE PATTERN

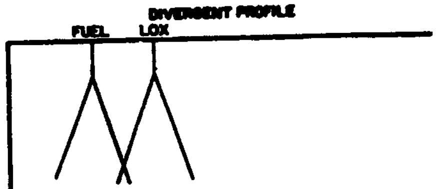


NO.	D	d	GROUP	Z	θ	Sp	Xjs	Xji
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
Not including 16 0.070 dia. doublets placed as indicated below								
-57	36.746	0.209	96/104	0.416	20°	1.11	[illegible]	0.284
-55	35.626	0.281	88/96	0.428	15°	1.17	0.744	0.254
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.284
Except LOX holes (0.209) next to all baffles								
-51	33.386	0.281	80/88	0.428	15°	1.22	0.744	0.254

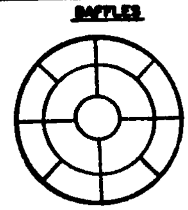
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.04	58.8
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (1500K)	55.7	138.9

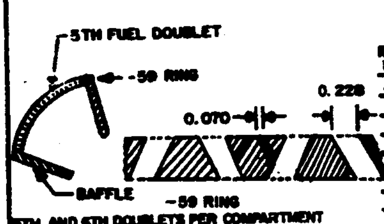
BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES





REMARKS: The injector is the same as 5867A3, U/N 081 except that 16 doublets of 0.070-inch diameter at θ = 38 degrees were placed in the outer fuel ring, two doublets per compartment.

Percent excess fuel on wall = 2.

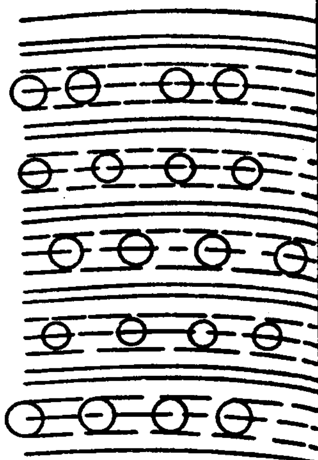
Percent film coolant = 4.7

Figure 20. Injector Unit 081, Type 5875A3

INJECTOR DESCRIPTION

UNIT 082, TYPE 5833XX, S/N

ORIFICE PATTERN

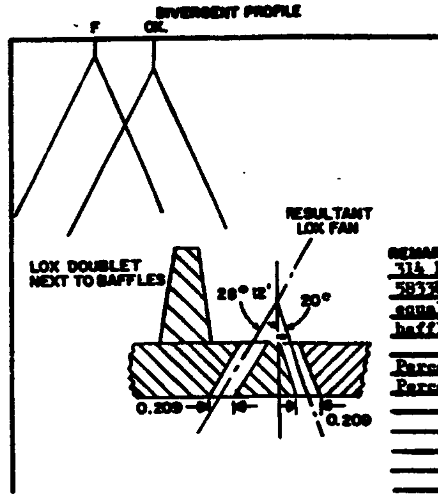


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjf
WALL	39.188							
	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
	35.620	0.281	88/96	0.416	15°	1.17	0.728	0.252
	34.506	0.209	88/96	0.374	28.2	1.13	0.349	0.153
	33.386	0.281	80/88	0.416	15°	1.17	0.728	0.252

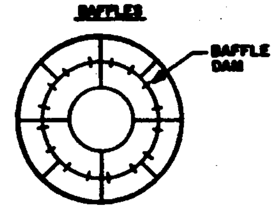
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.08	49.2
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (1500K)	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Same as unit 082, 5833UU; there are 314 LOX splitters; it differs from 082, 5833UU, in that 16 dams have been placed at equal intervals in the outer circumferential baffle

Percent excess fuel on wall = 2.2

Percent film coolant = 4.62

Figure 21. Injector Unit 082, Type 5833YY

[redacted]

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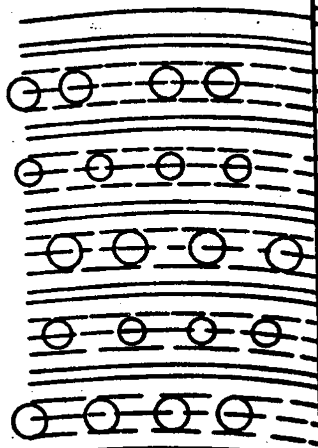
INJECTOR DESCRIPTION

UNIT 082, TYPE 5833D3, S/N

ORIFICE PATTERN

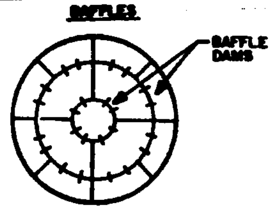


NO.	D	d	GROUP	Z	θ	Sp	XJc	XH
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.506	0.209	88/96	0.374	28.2	1.13	0.349	0.153
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

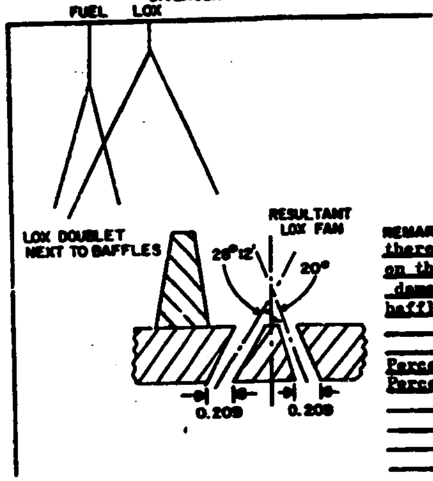
PATTERN GENERAL	FUEL	OXID.
ORIFICE AREA	85.08	49.2
RING GROOVE DEPTH	0.335	0.335
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (1500)	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

BAFFLES



DIVERGENT PROFILE



REMARKS: Same as unit 082, 5833YY, except there are eight circumferential baffle dams on the inner can; it also has 164 fuel ring dams; there are 314 LOX splitters and the baffles are programmed.

Percent excess fuel on wall - 2.2
Percent film coolant - 4.6

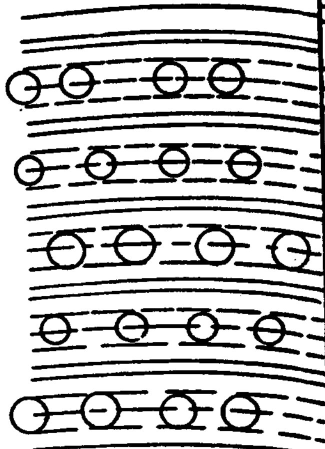
Figure 22. Injector Unit 082, Type 5833D3

[redacted]

INJECTOR DESCRIPTION

UNIT 082, TYPE 5833K3, S/N

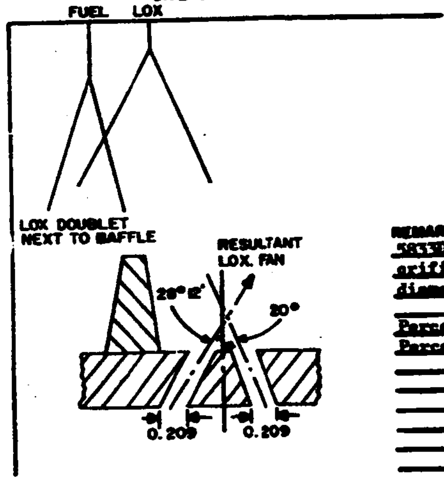
ORIFICE PATTERN



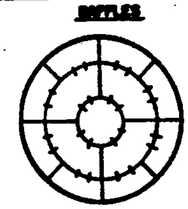
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xμ
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.428	15°	1.17	0.778	0.252
-53	34.506	0.209	88/96	0.374	28.2	1.13	0.349	0.153
-51	33.386	0.281	80/88	0.428	15°	1.22	0.778	0.252

PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	87.1	49.2
RING GROOVE DEPTH	0.338	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.211	
WALL GAP (OUTER ZONE)	[illegible]	
[illegible]	[illegible]	100

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches



BAFFLES



REMARKS: The injector is the same as unit 082, 5833D3 except the outer fuel ring has been orificed for 50 percent flow with 0.257-inch diameter tabs

Percent excess fuel on wall - 2.2
Percent film coolant = 2.3

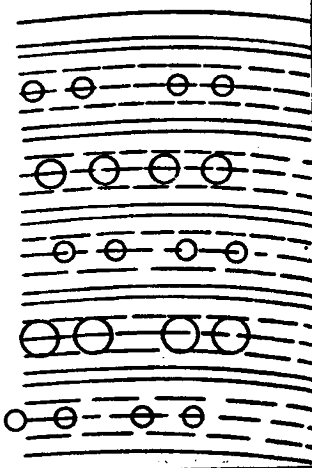
Figure 23. Injector Unit 082, Type 5833K3

[redacted]

INJECTOR DESCRIPTION

UNIT 092, TYPE 5874J3, S/N

ORIFICE PATTERN

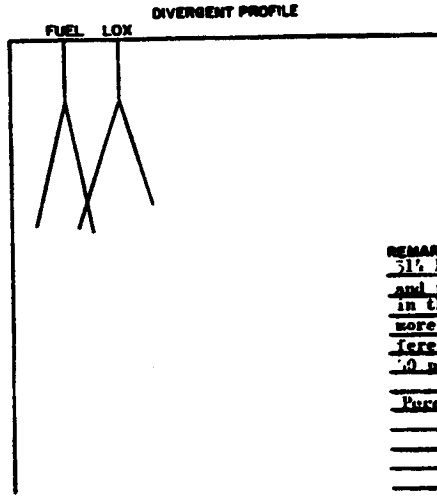


NO.	D	ε	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.138							
-59	37.766	0.159	96/104	0.416	20°	1.14	0.571	0.353
-57	36.746	0.209	96/104	0.416	20°	1.11	0.571	0.284
-55	35.626	0.159	88/96	0.428	15°	1.17	0.799	0.502
-53	34.506	0.242	88/96	0.416	20°	1.13	0.571	0.284
Except holes (0.209) next to baffles								
-51	33.386	0.159	80/88	0.428	15°	1.22	0.799	0.502

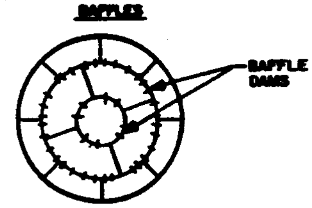
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	31.1	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
I. :. VELOCITY(1500K)	152.4	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Pase
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: Injector has deep LOX grooves and 51% LOX splitters; the baffles are rotated and programmed; 32 baffle dams were installed in the outer circumferential baffle; eight more were also placed in the inner circumferential baffle; outer ring orificed for 10 percent flow.

Percent film coolant = 6.1

Figure 24. Injector Unit 092, Type 5874J3

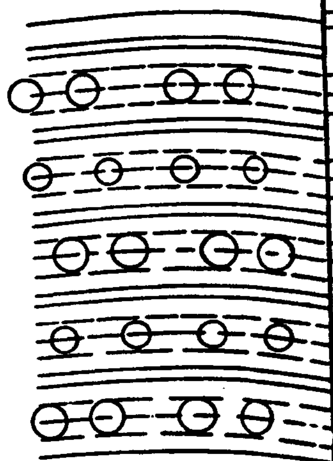
[redacted]

[redacted]

INJECTOR DESCRIPTION

UNIT X002, TYPE 5855ZZ, S/N

ORIFICE PATTERN

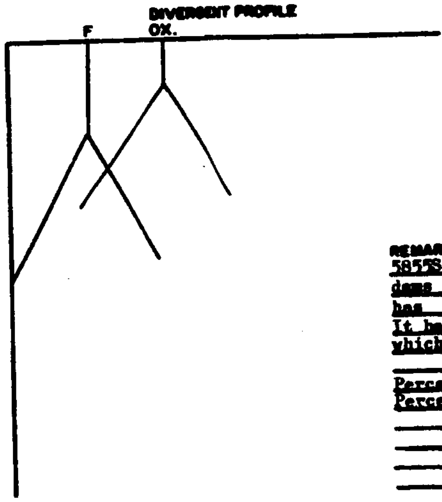


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjl
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.[illegible]58
-57	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.506	0.209	88/96	0.374	28.2	1.13	0.349	0.153
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

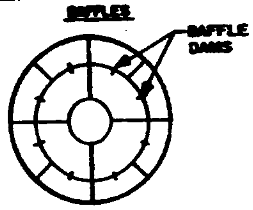
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	49.2
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
Inj. VELOCITY: 1500K	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is the same as [illegible] X0[illegible], 5855SS, except there are eight equally spaced dams in the outer circumferential baffle. It has deep LOX grooves and 314 LOX splitters. It has a grooved back for the LOX side baffles, which are attached to the dome.

Percent excess fuel on wall = 2.2
Percent film coolant = 4.61

Figure 25. Injector Unit X002, Type 5855ZZ

[redacted]

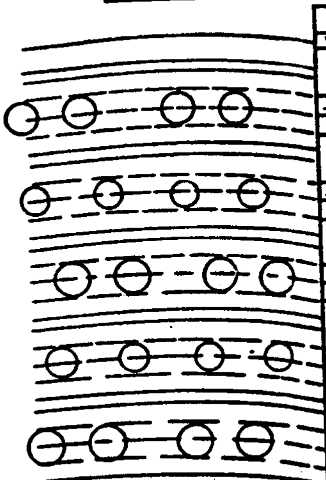
[redacted]

ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

INJECTOR DESCRIPTION

UNIT X002, TYPE 5855E3, S/N

ORIFICE PATTERN

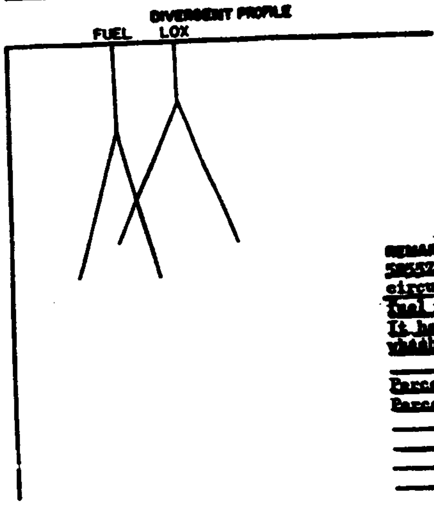


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xjl
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.2[illegible]
-57	35.746	0.209	96/[illegible]	0.374	28.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.2[illegible]
-53	34.306	0.209	88/96	0.374	28.2	1.13	0.349	0.153
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.2[illegible]

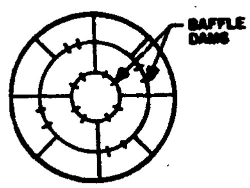
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	49.2
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
I.J. VELOCITY(1500K)	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is the same as U/N X002, 5855ZZ, except there are eight dams in the inner circumferential baffle. There are also 164 fuel ring groove dams and 314 LOX splitters. It has a grooved back for the LOX side baffles which are attached to the dome.

Percent excess fuel on wall = 2.2
Percent film coolant = 4.61

Figure 26. Injector Unit X002, Type 5855E3

[redacted]

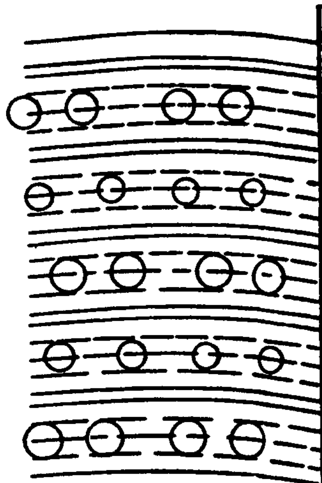
[redacted]

ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

INJECTOR DESCRIPTION

UNIT X002, TYPE 5855F3, S/N ____

ORIFICE PATTERN

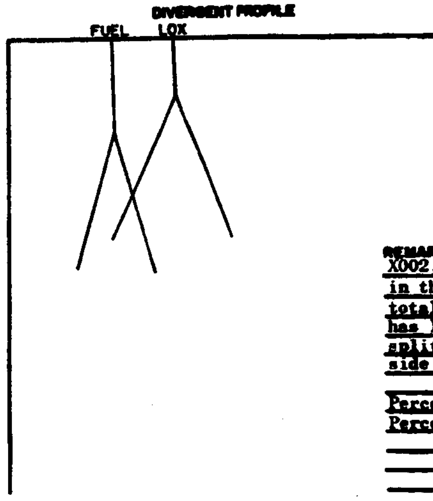


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.374	26.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.506	0.209	88/96	0.374	26.2	1.13	0.349	0.153
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

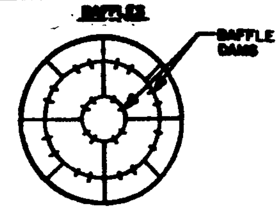
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.0	49.2
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY(1500K)	56	170

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Dams
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is the same as unit X002, 5855E3, except there are eight more dams in the outer circumferential baffle, making a total of 24 baffle dams. Like X002, 5855E3 it has 164 fuel ring groove dams and 314 LOX splitters. It has a grooved back for the LOX side baffles, which are attached to the dome.

Percent excess fuel on wall = 2.2
Percent film coolant = 4.61

Figure 27. Injector Unit X002, Type 5855F3

[redacted]

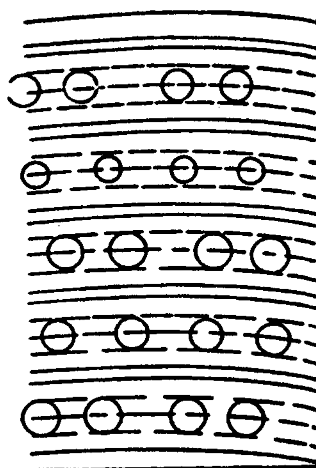
[redacted]

ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

INJECTOR DESCRIPTION

UNIT X002, TYPE 5871F3, S/N

ORIFICE PATTERN

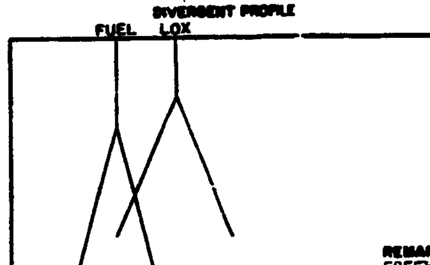


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.766	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.506	0.242	88/96	0.374	28.2	1.13	0.349	0.123
Except LOX holes (0.209) next to baffles								0.153
-51	33.386	0.281	80/88	0.416	15°	1.17	0.778	0.252

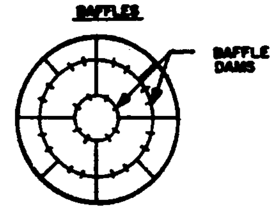
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
I.J. VELOCITY (1500)	55.7	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is the same as X002, 5855F3, except 412 LOX doublets have been drilled out to 0.242-inch diameter. Those LOX doublets in the outer LOX ring and those next to the baffles (305 groups) remain at 0.209-inch diameter. The injector has 314 LOX splitters and 164 fuel ring groove dams. There are a total of 24 baffle dams.

Percent excess fuel on wall = 2.2
Percent film coolant = 4.6

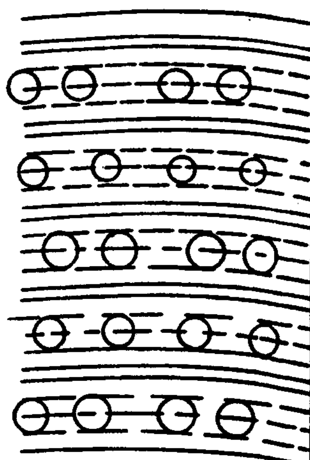
Figure 28. Injector Unit X002, Type 5871F3

[redacted]

INJECTOR DESCRIPTION

UNIT X002, TYPE 5876F3, S/N

ORIFICE PATTERN

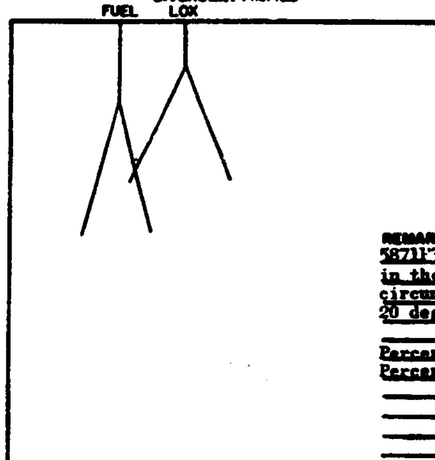


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.258
-57	36.746	0.209	96/104	0.374	28.2	1.11	0.349	0.153
-55	35.626	0.281	88/96	0.416	15°	1.17	0.778	0.252
-53	34.506	0.242	88/96	0.374	28.2	1.13	0.349	0.123
Except LOX holes (0.209) next to baffles								0.153
-51	33.386	0.281	80/88	0.416	15°	1.22	0.778	0.252

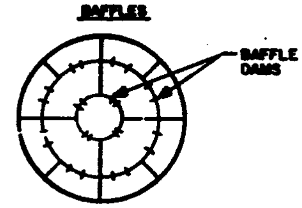
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	58.8
RING GROOVE DEPTH	0.538	0.538
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
I.J. VELOCITY (1500K)	55.7	138.9

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE



BAFFLES



REMARKS: The injector is the same as X002, 5871F3, except the angle of the LOX orifices, in the ring next to (but inside of) the inner circumferential baffle has been changed to 20 degrees.

Percent excess fuel on wall = 2.2
Percent film coolant = 4.6

Figure 29. Injector Unit X002, Type 5876F3

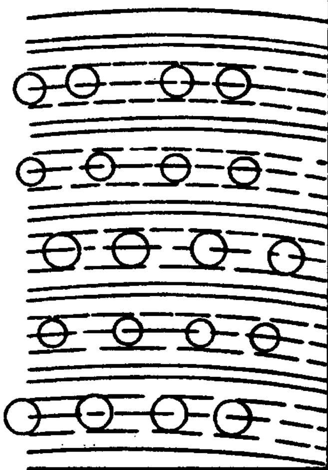
[redacted]

ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC

INJECTOR DESCRIPTION

UNIT X011, TYPE 5877D3, S/N

ORIFICE PATTERN

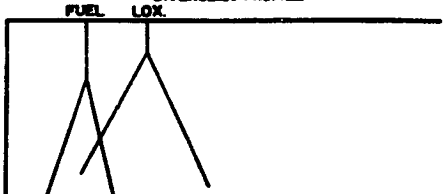


NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL	39.188							
-59	37.776	0.228	96/104	0.416	20°	1.14	0.571	0.256
-57	36.746	0.221	96/104	0.374	28.2	1.11	0.349	0.143
-55	35.626	0.281	88/96	0.428	15°	1.17	0.772	0.265
-53	34.506	0.221	88/96	0.374	28.2	1.13	0.349	0.153
-51	33.386	0.281	80/88	0.428	15°	1.22	0.772	0.265

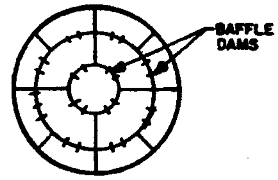
PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	85.1	50.6
RING GROOVE DEPTH	0.538	0.338
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.711	
WALL GAP (OUTER ZONE)	0.966	
INJ. VELOCITY (500K)	55.7	161.5

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	13
BAFFLE CONSTRUCTION	Wide Base
BAFFLE COOLANT	Fuel
BAFFLE LENGTH	3 Inches

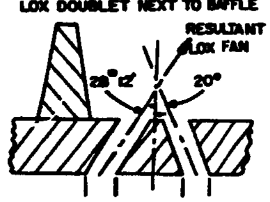
DIVERGENT PROFILE



BAFFLES



LOX DOUBLET NEXT TO BAFFLE



REMARKS: The injector is the same as unit 082, 5833D3, except that the LOX doublets in rings -9, -11, -31, -33 (those on either side of the circumferential baffles) are 0.141-inch diameter at 20 degrees half-angle, and the remaining LOX doublets are 0.221-inch diameter at 28 degree/12 min half-angle except those doublets next to radial baffles (described at left). There are 32 baffle dams, 164 fuel ring groove dams, and 314 LOX splitters, all placed as in 082.

Percent film coolant = 4.61

Figure 30. Injector Unit X011, Type 5877D3

[redacted]

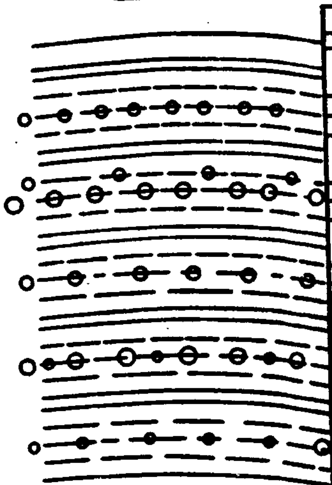
[redacted]

ROCKETDYNE • A DIVISION OF NORTH AMERICAN AVIATION, INC.

INJECTOR DESCRIPTION

UNIT________, TYPE 5581________, S/N________

ORIFICE PATTERN



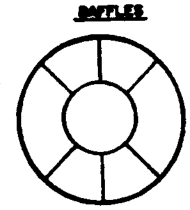
NO.	D	d	GROUP	Z	θ	Sp	Xjc	Xji
WALL								
	19.936	0.052	114	0.203	20°	0.101	0.279	0.208
	18.996	0.0312 0.089	114	0.203	20°	0.965	0.279	0.156
	18.058	0.0635	108/113	0.208	20°	0.502	0.286	0.198
	17.119	0.0781 0.113	54/59	0.416	* 20°	0.913	0.571	0.416
	16.180	0.0635	96/105	0.208	20°	0.485	0.286	0.198

PATTERN, GENERAL	FUEL	OXID.
ORIFICE AREA	5.26	8.625
RING GROOVE DEPTH	0.40	0.70
RING MATERIAL	Cu	Cu
WALL GAP (FUEL RING)	0.313	
WALL GAP (OUTER ZONE)	0.548	
I.J. VELOCITY ft/sec	129	128

BAFFLE DESIGN	
NUMBER OF COMPARTMENTS	7
BAFFLE CONSTRUCTION	0.375-Inch Thick
BAFFLE COOLANT	Bipropellant
BAFFLE LENGTH	3 Inches

DIVERGENT PROFILE

BAFFLES



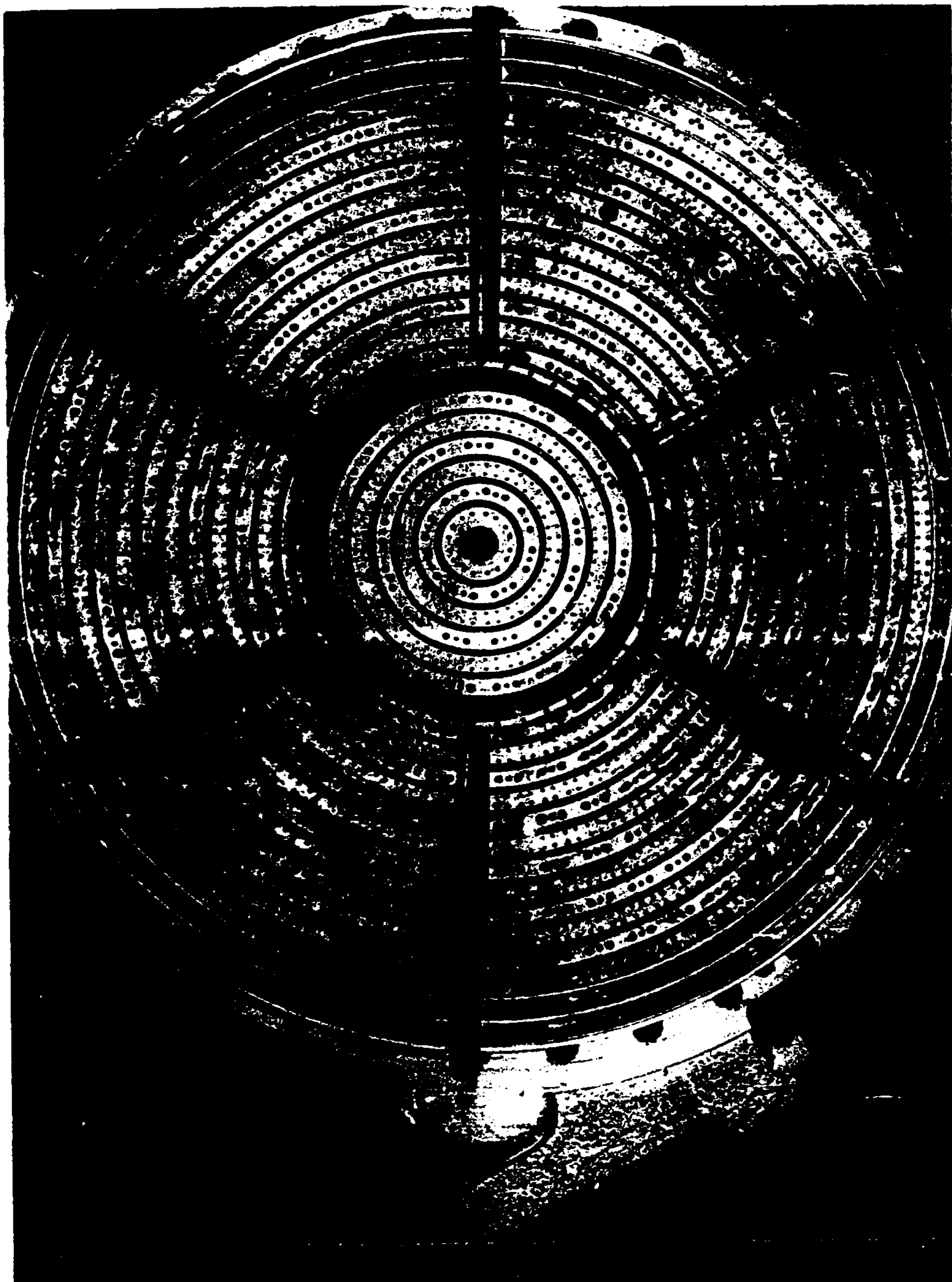
*Shower Head

REMARKS: 114 fuel and LOX groups in outer two rings; no film coolant orifices.

Figure 31. Injector Type 5581

[redacted]

[redacted]



1CJ45-4/21/64-S1

Figure 32. Injector Type 5582

[redacted]

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[redacted] [redacted]

B

Test No.	Injector Type	Date	Test Duration, seconds	Sea Level Thrust, 1000 pou
15115	5581	4-1-64	30.8	199.1
15116	5581	4-1-64	30.9	199.3
8752	5582	4-2-64	31.0	205.3
8753	5582	4-2-64	30.6	205.6
8754	5582	4-2-64	30.8	206.0
8755	5582	4-2-64	30.9	206.5
8756	5582	4-3-64	9.0	--
8757	5582	4-3-64	5.7	--
8758	5582	4-3-64	31.0	206.8

NOTES: 1. Damp time measured from P_c tr

2. Test 8757 self-triggered and
detonated and damped in 12 mi

Test 8758 self-triggered and
detonated and damped in 15 mi

[redacted]

TABLE 3

UCTED DURING APRIL, 1964

Sea-Level Ratio Mixture	Average P_c, psia	Bomb Disturbance, grains	Damp Time, milliseconds	η_c*
2.200	680.6	--	--	97.4
2.192	681.4	--	--	--
2.236	703.3	50	15	97.2
2.240	707.6	50	20	97.4
2.23	709.8	--	--	--
2.229	710.6	--	--	--
--	--	50	33	--
----	--	See Note 2	See Note 2	--
2.245	707.0	See Note 2	See Note 2	97.0

milliseconds. Bomb also

illiseconds. Bomb also

[redacted]

The purpose of testing injector type 5582 was to evaluate the effect of double-row fuel orifices, LOX triplets, 90 groups of orifices in the outer two rings, and low fuel injection velocity.

This injector damped five bomb disturbances within 33 milliseconds. Probable self triggers were noted in two of the damped tests prior to the bomb detonations for 3 and 10 milliseconds. The amplitude of these self-induced pops was approximately 265 psi peak to peak. The c* efficiency of these tests was above 97 percent. The high performance of this injector was attributed to the outer 90 groups, and stability was attributed to the low fuel injection velocity. The significant achievement of this injector was the combination of matching double-row fuel doublets and single-row LOX triplets in achieving stability.

Program Contributions for F-1 Application

The most significant contributions of the H-1 for F-1 Stability Program toward the development of high performance and dynamic stability include:

1. Large fuel orifices or lowered fuel injection velocity is beneficial for dynamic stability. (In later testing it was clearly demonstrated that the lowered velocity with small orifices was actually more beneficial than large orifices.)
2. The high sensitivity of the outer zone of an injector with respect to stability was clearly demonstrated by plugging the outer two rings and achieving consistent one-cycle damping. The performance degradation incurred with this modification, however, was prohibitive, and the concept was not incorporated in production engines.
3. The ability to conduct long-duration tests without film or body coolant orifices was first demonstrated during the H-1 for F-1 Stability Program.

4. A limited investigation of propellant additives showed no appreciable effect of additives on performance or stability and hence, expensive and time consuming investigation on the full-scale F-1 engine system was avoided.
5. The need for baffles was again re-emphasized through an attempt to show improved flat-face stability on a low fuel velocity injector. The system self triggered at 90 percent chamber pressure and showed no sign of damping.
6. The sensitivity of the injector pattern in the outer zone with respect to performance was illustrated. By increasing the number of groups in the outer two rings from 60 to 90 and reducing film coolant, an appreciable change in specific impulse was observed (7 seconds). It was recommended that this concept be employed in some experimental F-1 injectors for further evaluation.

COMPONENT TEST STAND 2A CALIBRATION

Injector performance and pressure drop data obtained at test stand 2A, when compared with data obtained on engines using the same injectors, revealed discrepancies that could not be accounted for. It became apparent that the original test stand 2A flowmeter calibrations conducted at Cornell University were no longer valid.

The major problems encountered at test stand 2A were apparently a result of the inadequacy of the switch gage systems. The two main problems associated with the use of the switch gage systems were:

1. The apparent specific gravity of the switch gage floats was only slightly less than that of the propellants. Consequently, there was excessive "bobbing" of the floats owing to a low restoring force.

[redacted]

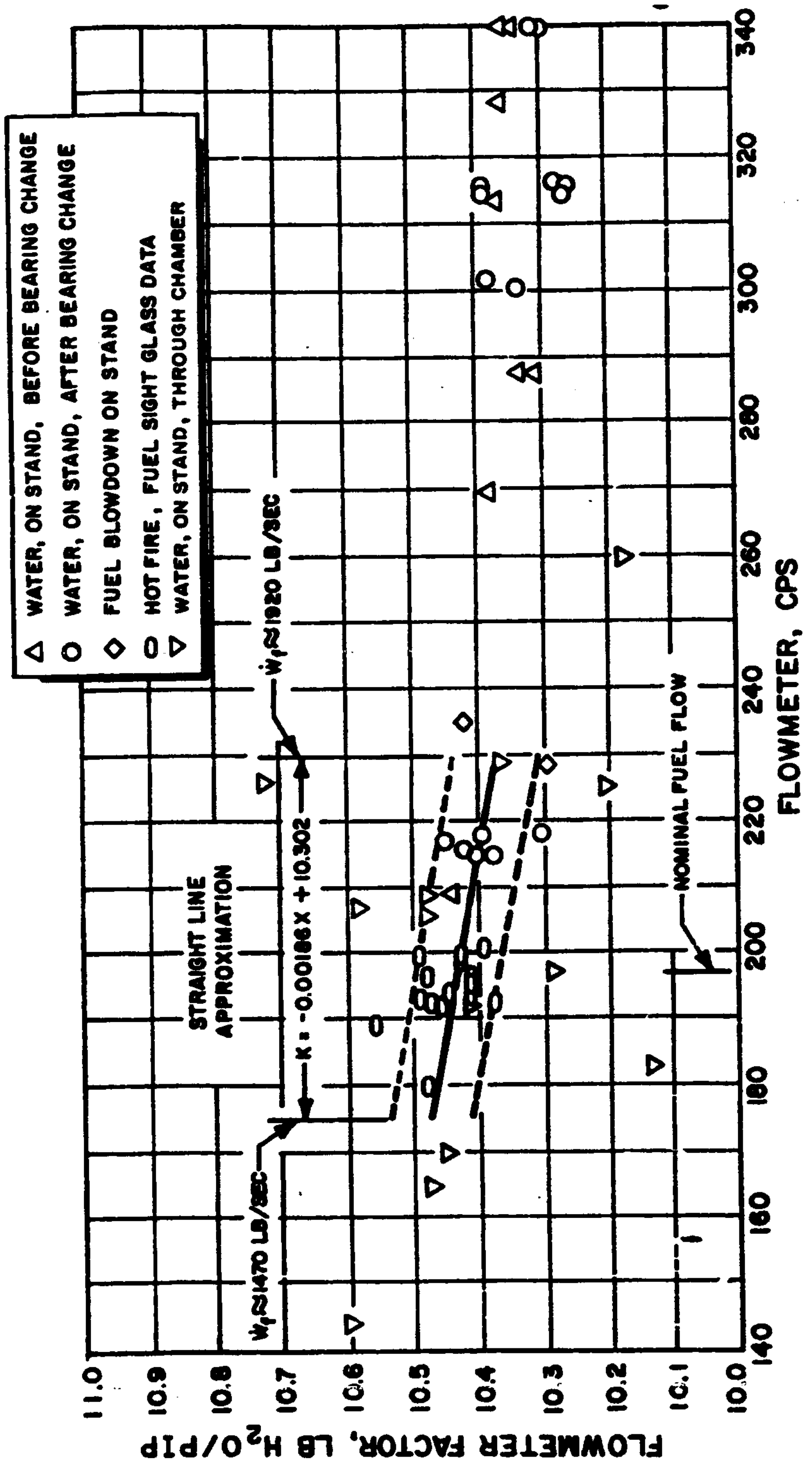

Figure 33. Test Stand 2A, Fuel Flowmeter Calibration

[redacted]

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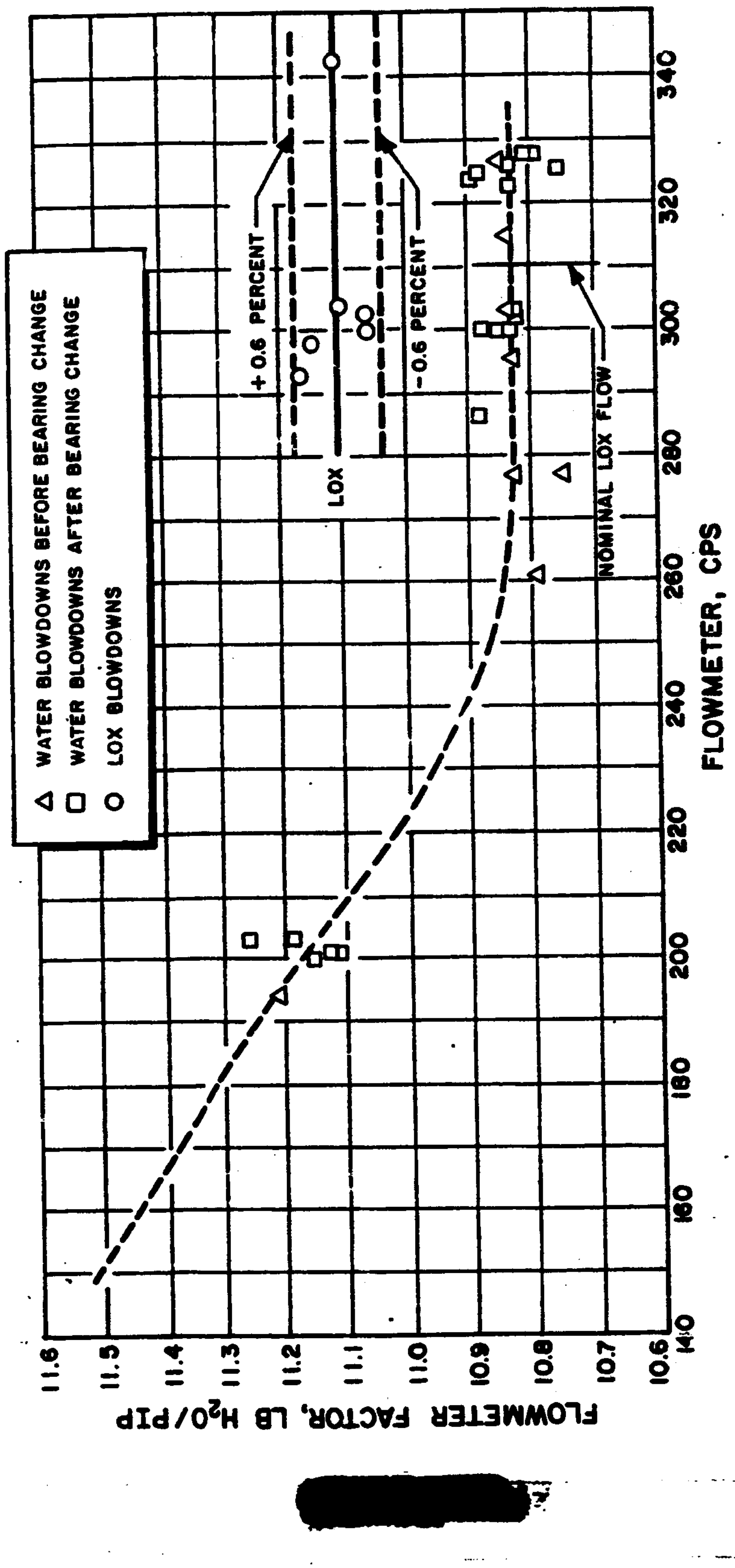


Figure 34. LOX Flowmeter Calibration

[redacted]

A modified LOX rotor was machined and installed in the LOX flowmeter to solve the problem of rotor blade cracking with the original design rotor. This modification required recalibration of the LOX flowmeter. A flowmeter factor of K = 11.375 lb H_2O/PIP was obtained from a series of eight LOX blowdowns with the modified rotor configuration (Fig. 35). It was assumed again that the flowmeter was being operated in a linear region.

HYDRODYNAMICS

During this period, particular attention was given to the following hydrodynamic studies:

1. Orifice discharge coefficient evaluation
2. Evaluation of proposals for improving the compatibility of injector 081
3. Analysis of outer three fuel rings of injector 073
4. Spray and fan formation studies

Phase I of the effort on discharge coefficient (C_d) work was completed. This phase consisted of evaluating all of the common types of orifice configurations used in F-1 stability investigation. Entrance condition for these types was either rough-undeburred or sharp-edged deburred. In addition to these, several other special types such as ASME orifices were tested during this portion of the program. A list of all orifice types tested is given in Table 4. Also, an example of a C_d vs differential pressure plot is shown in Fig. 36.

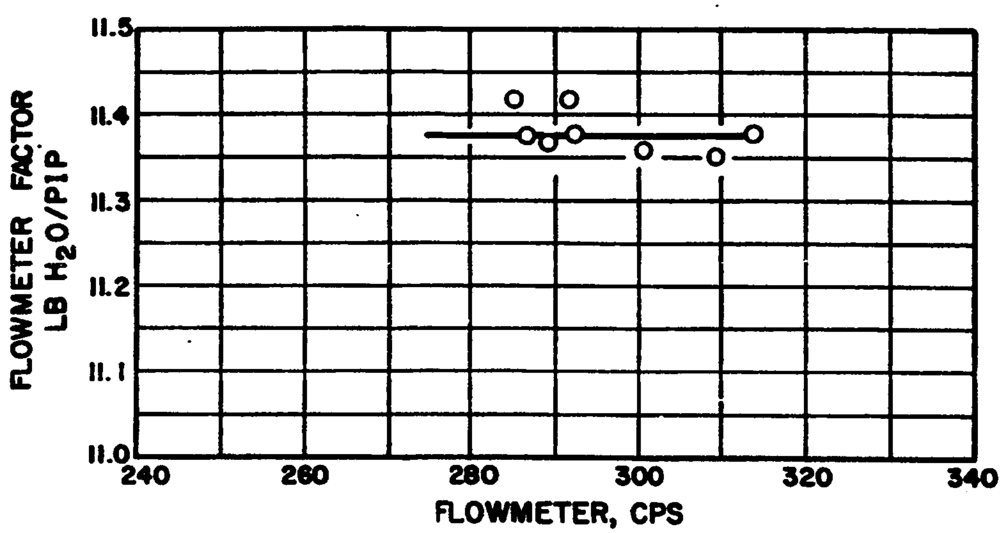


Figure 35. Test Stand 2A LOX Flowmeter Calibrations (Modified Rotor)

TABLE 4

ORIFICE TYPES

Orifice Diameter, inches	Entrance Condition	LOX (L) or Fuel (F)	Doublets (D) or Triplets (T)	C_D at Rated Conditions*
0.1285	Deburred	F	D	0.791
0.147	Deburred, countersunk	L	T	0.962
0.159	Deburred, countersunk	F	D	0.872
0.1695	Deburred, countersunk	L	T	0.926
0.177	Deburred	L	T	0.811
0.185	Deburred, countersunk	L	T	0.888
0.209	Deburred	L	D	0.775
0.2187	Undeburred	L	T	0.712
0.221	Undeburred	L	T	0.784
0.228	Deburred	L	T	0.870
0.228	Drilled out ASME	F	D	0.821
0.228	Simulated drilled out ASME	F	D	0.828
0.234	Undeburred	L	T	0.892
0.281	Deburred	F	D	0.730
0.348	Deburred	F	D	0.748

*38 gpm for LOX orifice groups and 20 gpm for fuel orifices unless otherwise stated

[redacted]

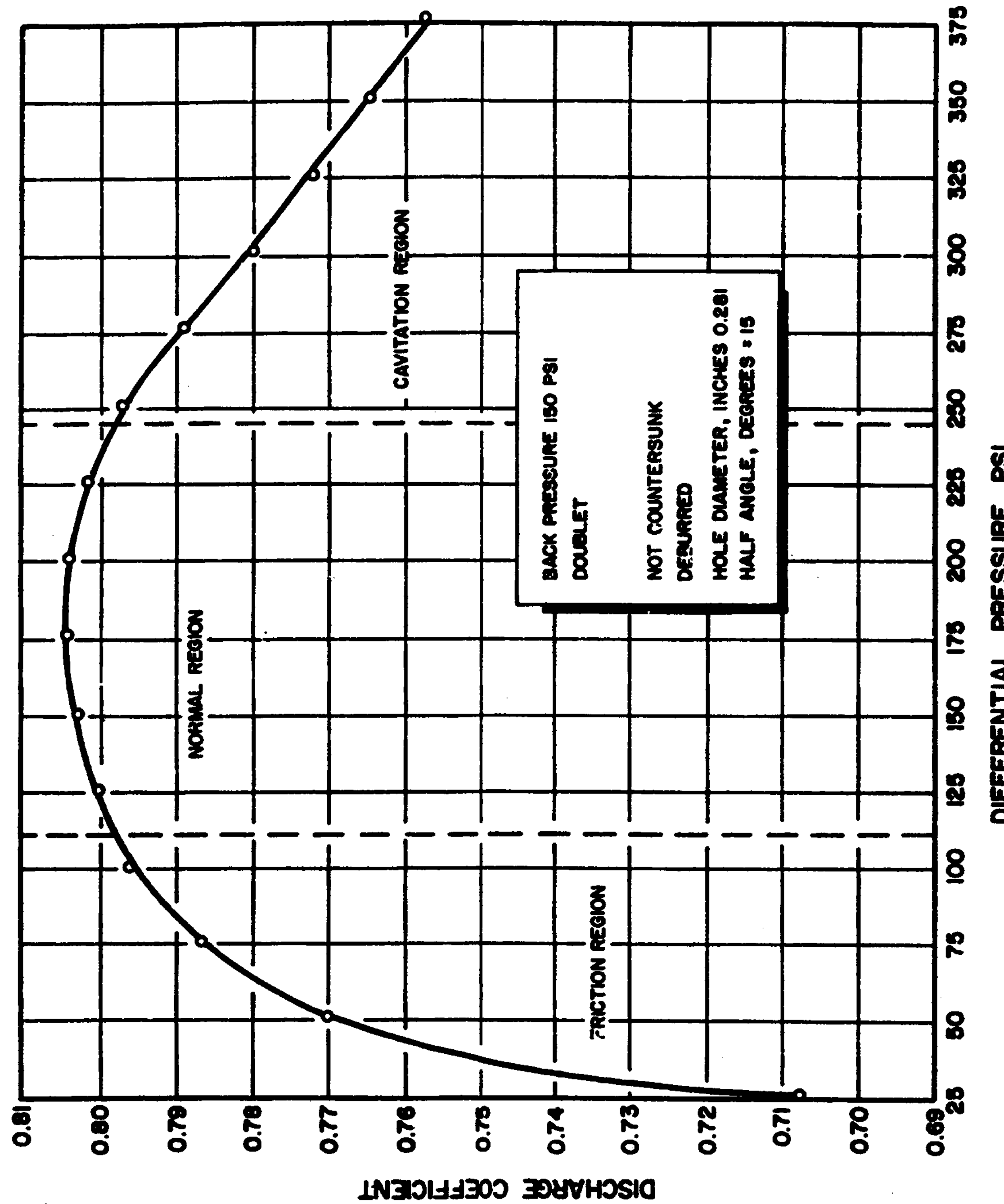


Figure 36. Discharge Coefficient vs Differential Pressure

[redacted]

The hydrodynamics flow device was used to evaluate several proposals for improving the compatibility of injector 081. Among the concepts evaluated were: (1) staked impinging orifices with and without a milled slot to provide more circular cross-section fans, and (2) additional injection elements between doublets in the outer ring to fill any gap between fans in the problem area. The additional elements tested were 76-degree impinging doublets drilled into the existing orifice holes, igniter housing heads brazed into the ring, and recessed impinging doublets oriented normal to the existing pairs. The 76-degree impinging doublets appeared from the flow studies to be adequate, and were selected because of their simplicity as a modification to an existing injector.

The three outer fuel rings of injector 073 were flow tested and analyzed. The data showed that within a given compartment, maximum and minimum doublet group flows varied as much as 100 percent. Similarly located orifice groups from one compartment to another have always showed flow capacity within a 30-percent band (±15 percent) about the average of the entire ring flow. Figure 37 shows the flow per doublet in the first fuel ring of injector 073.

Spray and fan formation studies with impinging orifice groups were conducted during this period. Fastax films of sprays discharging into atmospheric pressure from plates installed on the hydrodynamics flow fixture were taken from two positions 90 degrees apart.

Attempts to obtain spray photographs under back pressure in the gaseous nitrogen environmental tank were unsuccessful. Excessive back splash and improper lighting caused by the placement of view ports in the tank yielded very poor pictures. For this reason the atmospheric discharge medium was chosen until tank modifications could be made.

[redacted]

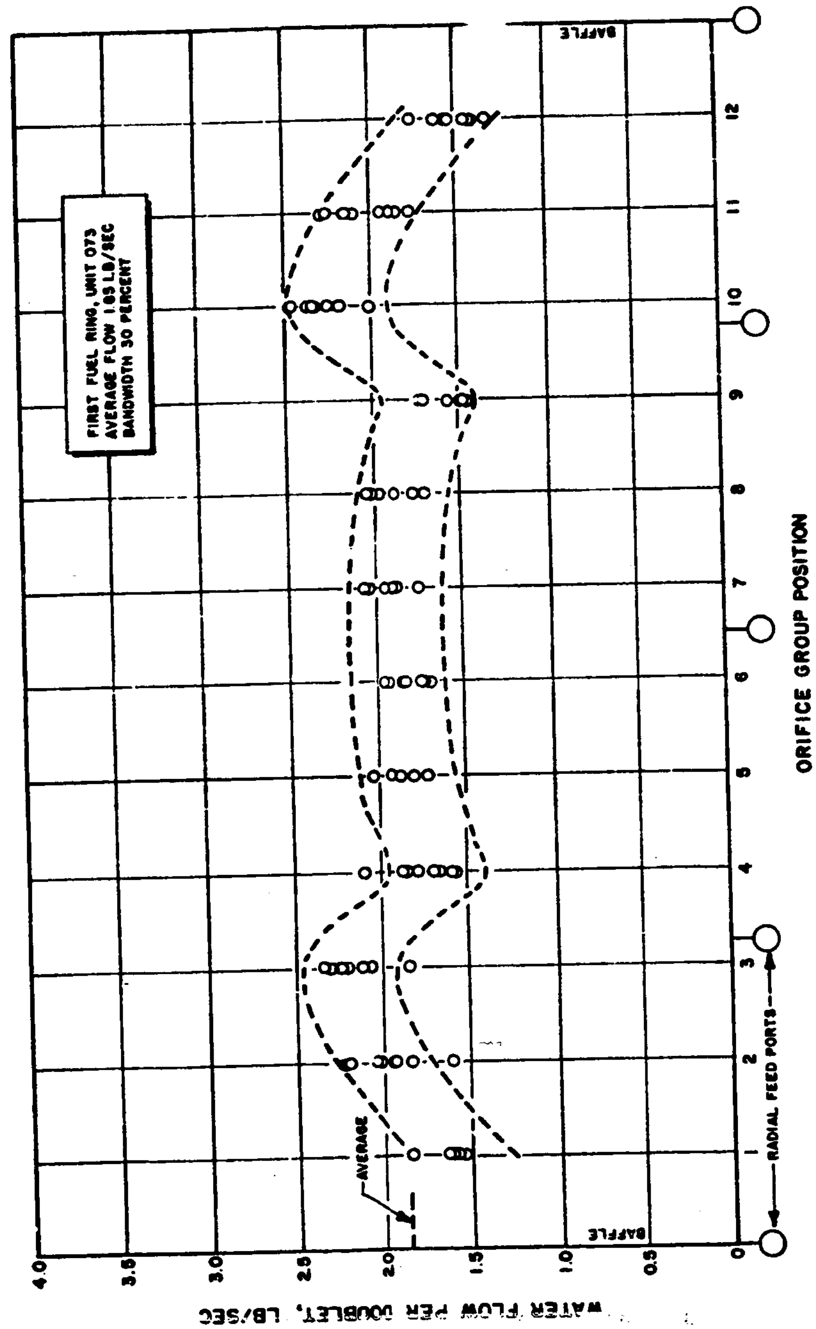


Figure 37. Flow Per Doublet in First Fuel Ring of Injector 073

[redacted]

DESIGN

Design activities were concentrated on the development of an FRT injector configuration that would meet or exceed performance and combustion stability contractual requirements. The effort was divided into two general categories: the design of new injectors, and the modification of existing injectors.

The new injector designs were basically configurations that resulted from a series of modifications which had proved beneficial on existing injectors. The two new injectors, X051 and X056, were similar to the 081 and 092 configurations, respectively. The major difference between injector X051 and 081 was the depth of the oxidizer ring grooves, which was 0.2 inch deeper on injector X051. Also, on injector X051 the fuel ring and baffle dams were incorporated at the time of assembly and were brazed in place to obtain a seal. The dams used on injector 081 were added after assembly by installing them through slots machined in the fuel rings and baffles. To effect a seal at each location, a metal-to-metal fit was maintained between the dam and ring groove surfaces. The slot-to-dam interfaces were then welded to complete the seal.

Injector 092, as fabricated, had small-diameter fuel orifices to evaluate the effects of high fuel injection velocity on performance and combustion stability. The injector also had the outer radial baffles rotated 22.5 degrees such that the inner and outer radial baffles were not in line. This was accomplished to improve the strength of the baffle system. The test results (Table 2, tests 158 and 159) showed good c* efficiency, but a long damp time and considerable radial baffle burning was found after test 159. The fuel orifices were then enlarged and the injector was re-tested (tests 194 through 197). The results are given in Table 2

Injector X002 and oxidizer dome E001 were modified by the addition of four radial dome dams. These dams were welded to the top of the dome cavity and sealed against Teflon seals placed in grooves on the back of the injector. They divided the dome cavity into four sealed segments.

Posttest inspection indicated good sealing had been achieved. Photographs of the dome and injector are shown in Fig. 38 and 39.

Injector X002 is a 13-compartment, 3-inch high, in-line baffle configuration with deep oxidizer ring grooves. The orifice pattern has countersunk doublets 0.209- and 0.343-inch in diameter with a 56 degree 24 minute impingement angle. The fuel doublets are 0.281-inch in diameter, with a 30 degree impingement angle; however, the fuel doublets in the outer ring are 0.228-inch diameter with a 40 degree impingement angle. The injector does not have body or film coolant orifices. This injector has 314 oxidizer feed passage splitters. A cutaway sketch of a splitter installed is shown in Fig. 40. The locations of these splitters are shown in Fig. 41. The locations shown are typical for all injectors having 314 splitters.

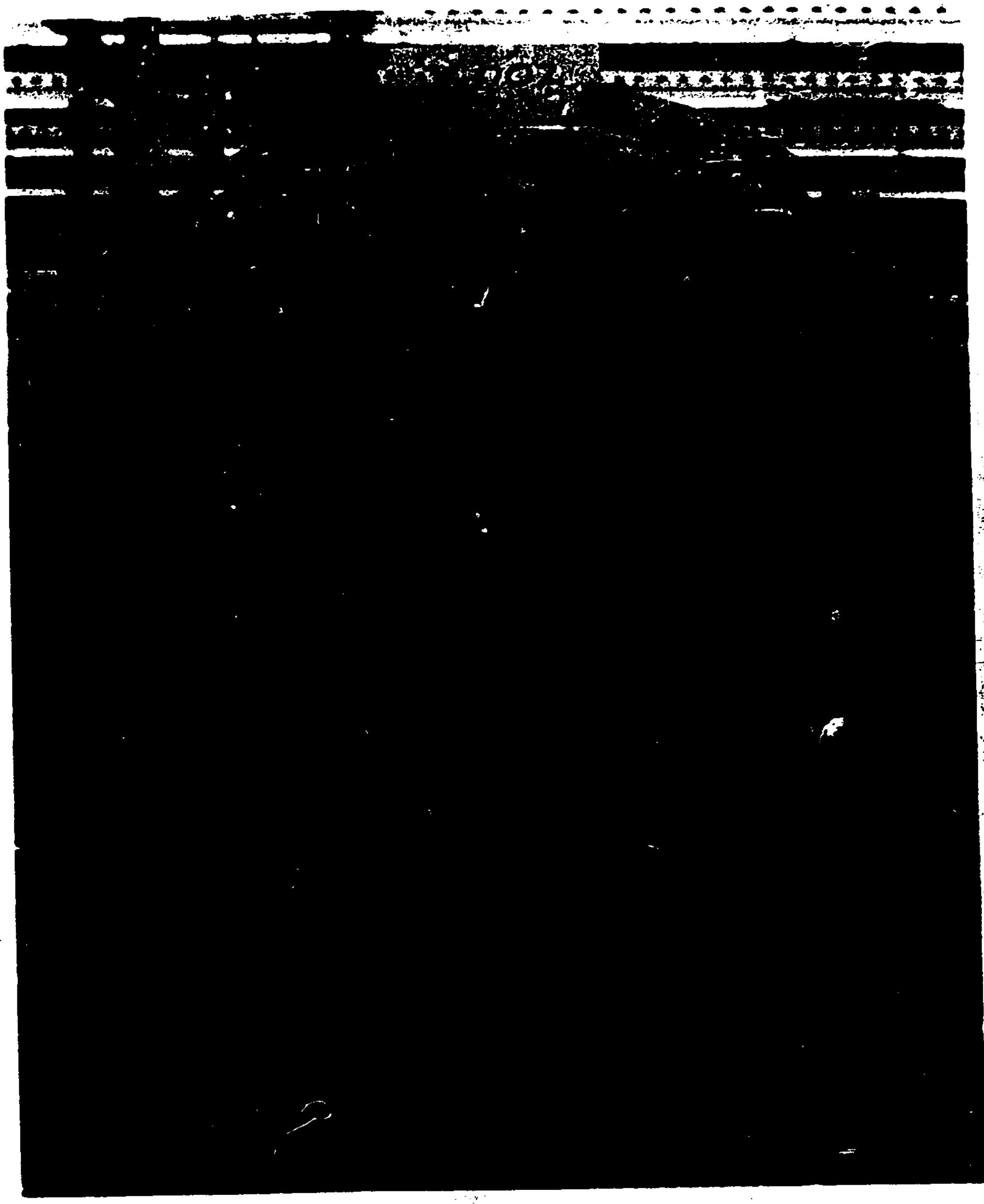
INJECTOR OXIDIZER DOME

To reduce the pressure drop of the F-1 engine system, considerable study of the oxidizer dome was made. Calculations for the existing dome indicate excessive pressure drop in the two tubular Y-shaped radial inlets. A photograph of this configuration is shown in Fig. 42. The design study revealed that approximately 65 percent of the 125 psi pressure drop through the dome could be eliminated by using expanding area inlets which faired into the torous manifold. The original experimental low differential pressure design was such that no long lead-time tooling was required and fabrication could be expedited. The dome is shown in Fig. 43.

1DB45-4/13/64-C1B

Figure 38. Oxidizer Dome E001

[redacted]



1DB41-5/26/64-C1D

Figure 39. Injector Unit X002

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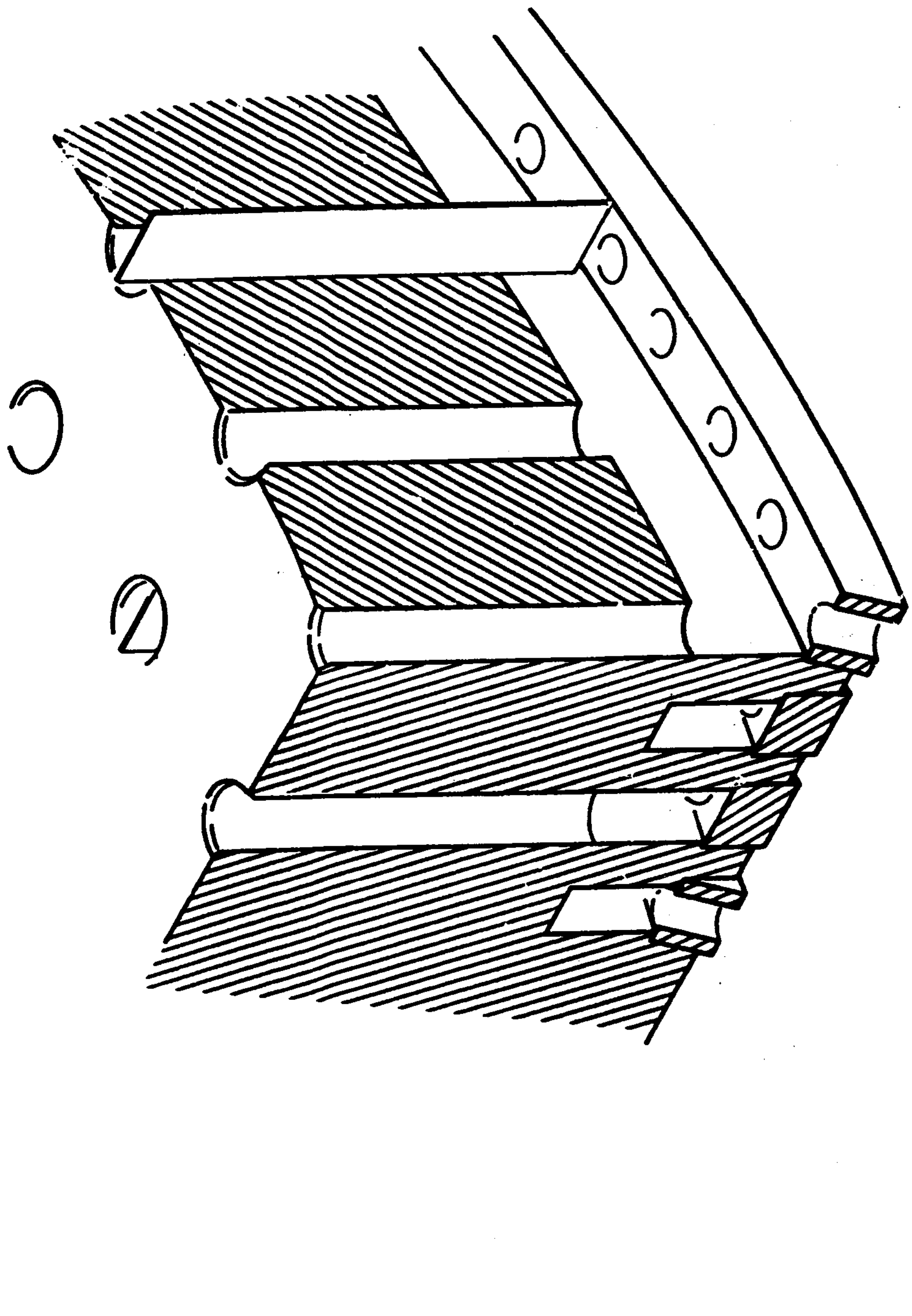

Figure 40. Splitter Installed

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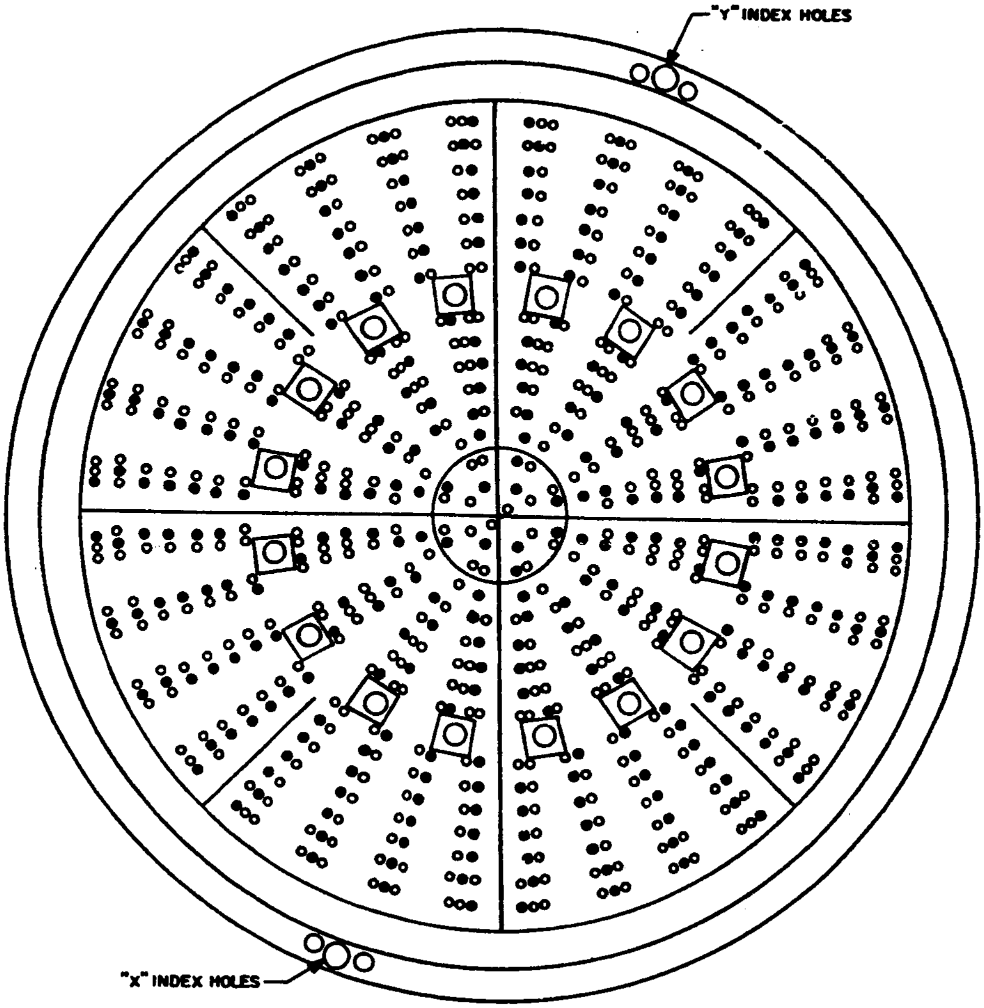

Figure 41. Location of Oxidizer Splitters for 314 Splitter Configuration

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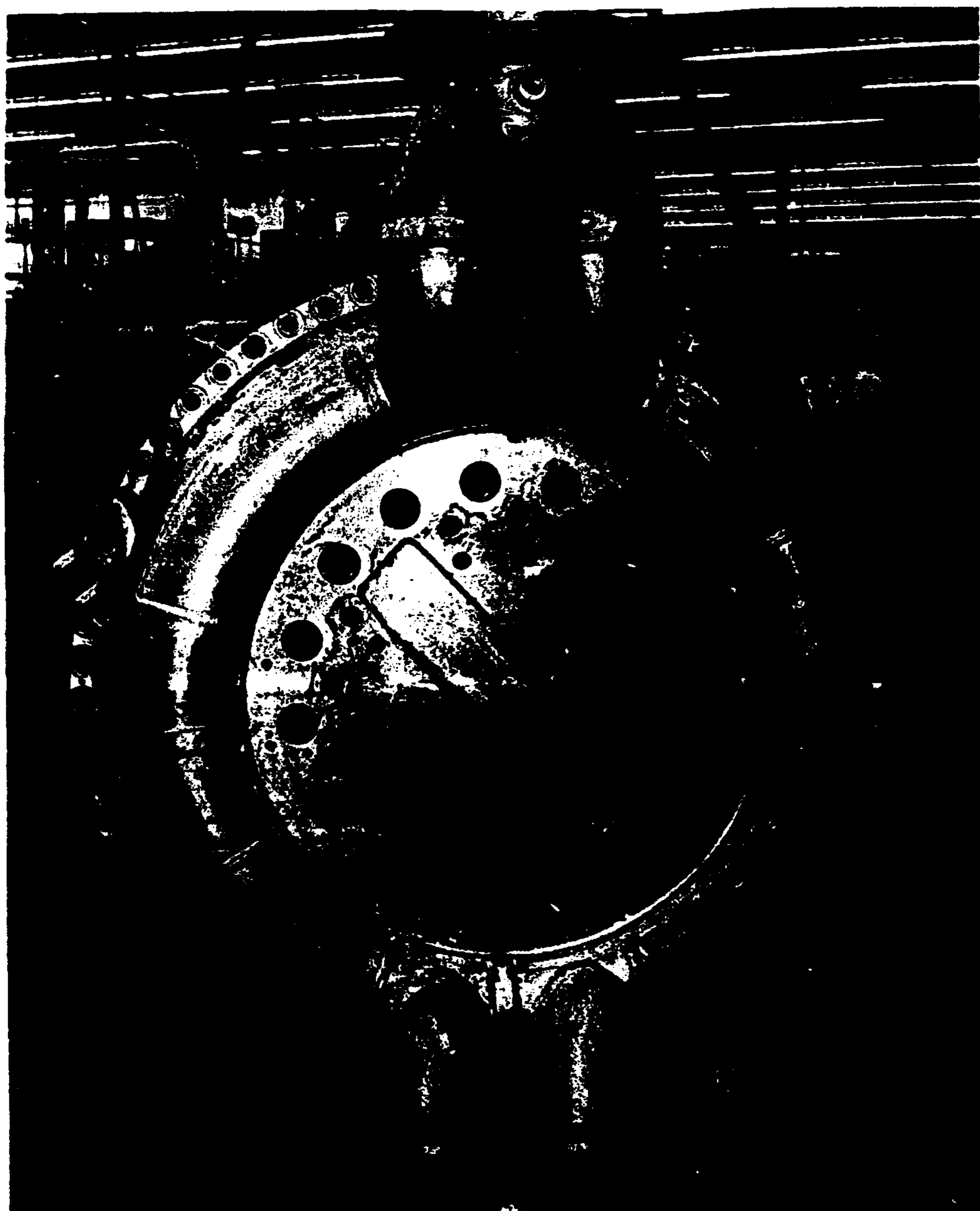

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Figure 42. Injector Dome With Y-Shaped Inlets

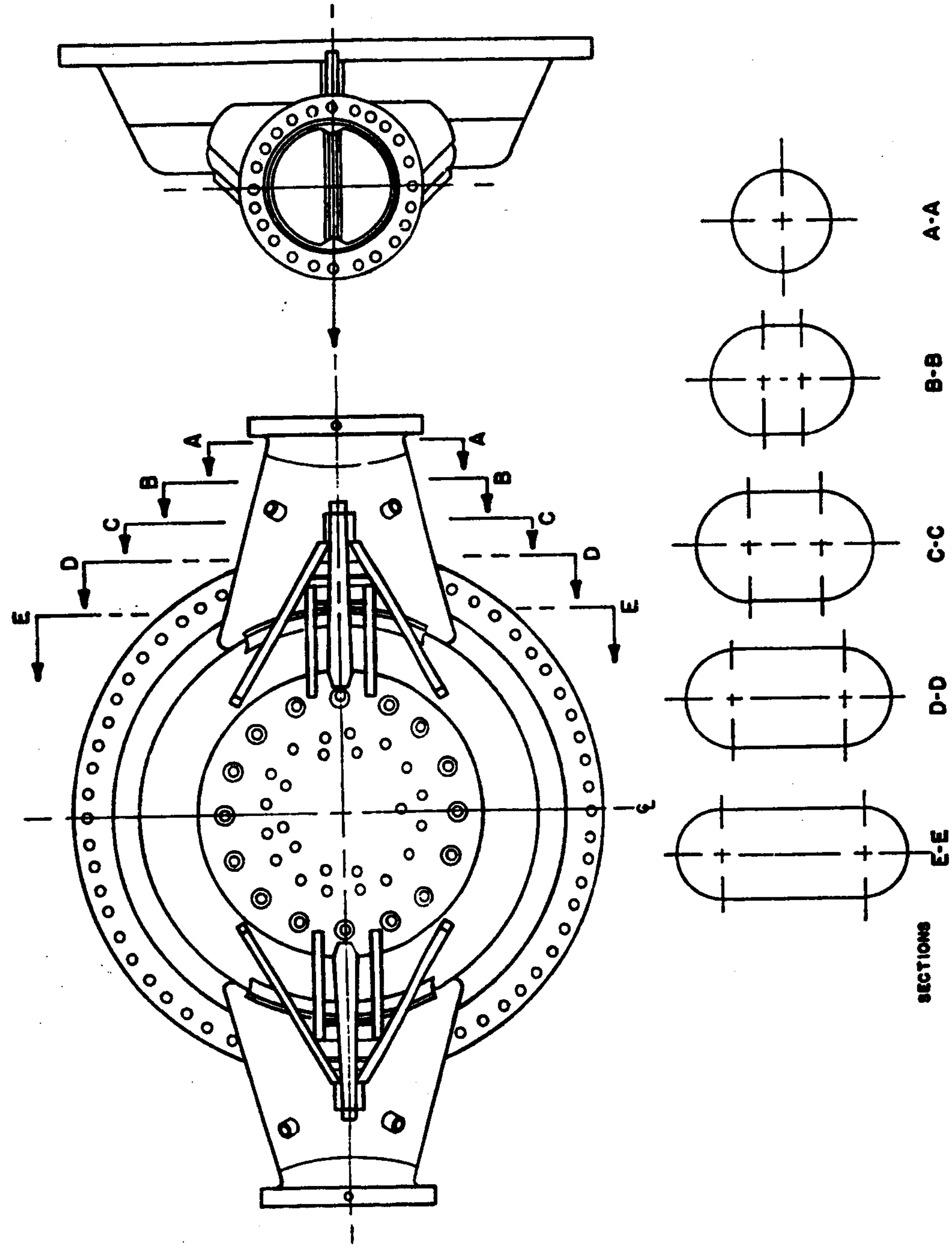

Figure 43. Experimental Low-Differential-Pressure Oxidizer Dome

This design was initially tested in April and an actual pressure drop reduction of 86 psi was realized. A follow-on production design (Fig. 44) was made to eliminate the external bracing and the associated welding. The production dome required considerable tooling, but reproducibility of the flow contours will be more repeatable than the hand formed experimental models.

ACOUSTIC LINER

The acoustic liner was designed to be concentric with the upper cylindrical and choke-ring sections of the F-1 gas generator body. The inner surface was covered with an array of triangularly spaced holes 0.035-inch in diameter and 0.180-inch deep. These led into individual resonator cavities 0.250 inch in diameter and 0.500-inch deep. This required depth necessitated counterboring and matching 0.250-inch-diameter holes on the inner surface of the body. Because of machining difficulties, the upper three rows of holes, which lay in the cylindrical section of the body, were not drilled, but were replaced by a continuous groove 0.125-inch deep. Bleed holes were drilled in the resonator cavities to vent any accumulation of unburned fuel that might collect there. Figure shows the liner geometry.

The resonant frequency was adjusted to match that of the calculated first tangential mode within the cavity, 1990 cps.

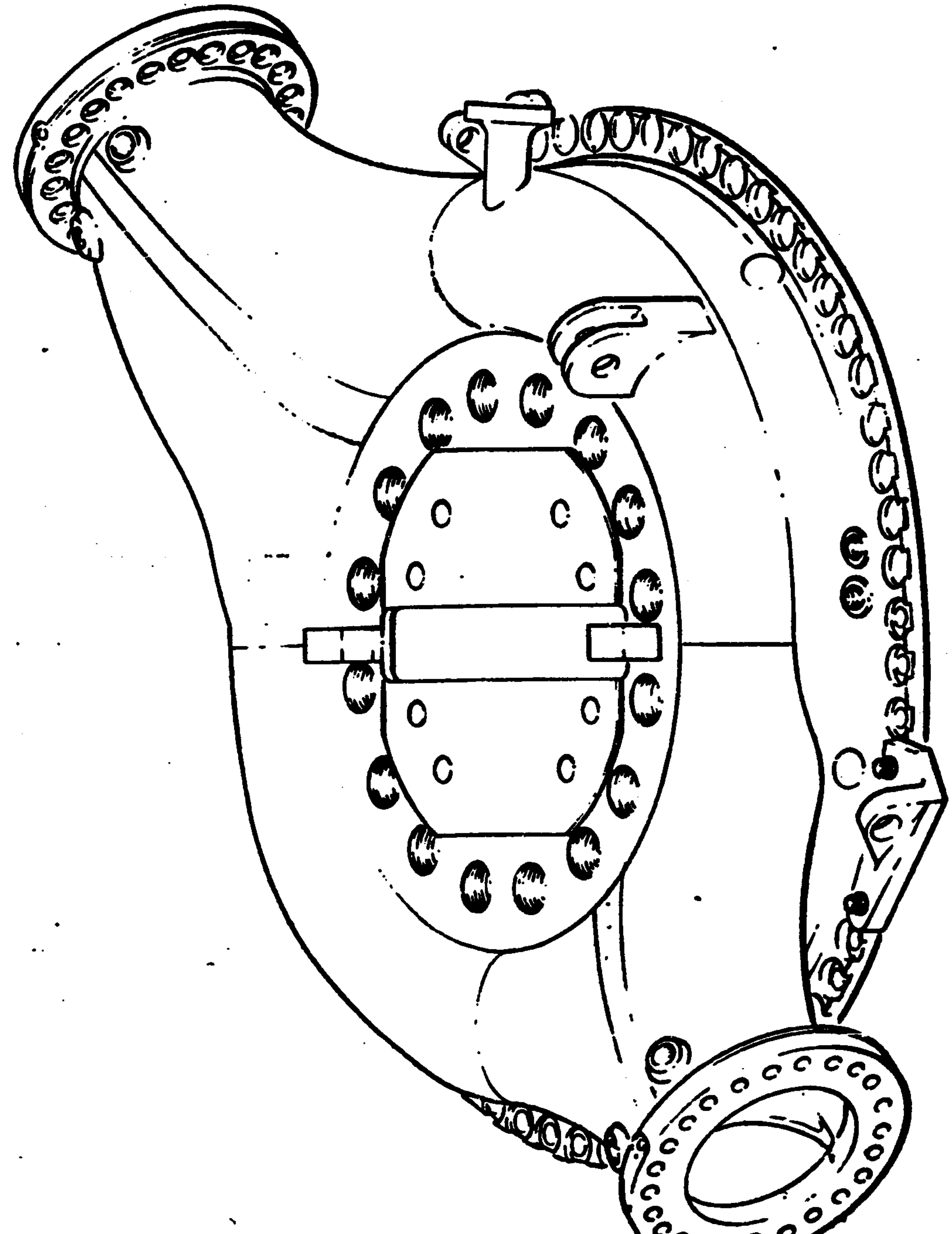

Figure 44. Production Low-Differential-Pressure Oxidizer Dome

EXPERIMENTAL PROGRAMS

Several experimental programs were conducted during this quarter. The programs were as follows:

1. Single-Element Spud Program
2. Acoustic Liner Program
3. Bomb Development Program
4. Feed System Pulsing Program

SINGLE-ELEMENT SPUD PROGRAM

The single-element spud program conducted by the Research Department had been completed by the beginning of this period. Plans were made to use the Neosho, Missouri Facility to test single-element spuds. The purpose was to determine the operating characteristics and performance of various spuds. On 12 May 1964, the first spud test was conducted at Neosho. Three basic parameters were measured and were recorded on standard oscillographs: chamber pressure, thrust, and flowrate. In addition, the feed system differential pressures, LOX temperature, propellant tank pressure, injector differential pressures, and inlet pressures were recorded.

Accumulated tolerances of the measuring system placed a ±6-percent limitation on accuracy when computing performance. Although this band could normally be narrowed by plotting the data from repeated testing, a problem of variation in mixture ratio between tests existed.

In an effort to minimize the possibility of errors, chamber pressure was measured at three points on the injector face, and thrust was recorded by two instruments. However, the data were scattered, and an average chamber pressure and average thrust were used. The values for the measured thrust, however, seldom coincided with the calculated values of thrust using measured chamber pressure.

A thorough investigation to resolve these problems was initiated. The investigation revealed that the thrust measurement system was in error. The system was measuring an additional side load, thereby increasing the total measured thrust. It was decided to install a new thrust measurement system. Other problems, however, still remained to be resolved at the end of this period.

The data for this period are considered to be unsatisfactory and are not presented here. However, illustrations of spud elements tested during this period are presented in Fig. 45 through 53.

ACOUSTIC LINER PROGRAM

During April, 1964, the Acoustic Liner Program was initiated. The program was a result of findings made at United Aircraft, which verified the feasibility of using an acoustic liner to suppress combustion instability.

It was decided to design an acoustic liner suitable for use with Rocketdyne's F-1 gas generator injector. It was known that a certain injector with an unlike-impinging triplet was inherently rough. Consequently, the injector was chosen for use with the liner to demonstrate feasibility. The liner was designed to replace the outer fuel ring in the gas generator injector. Figure 54 is an illustration of the acoustic liner in the gas generator.

[redacted]

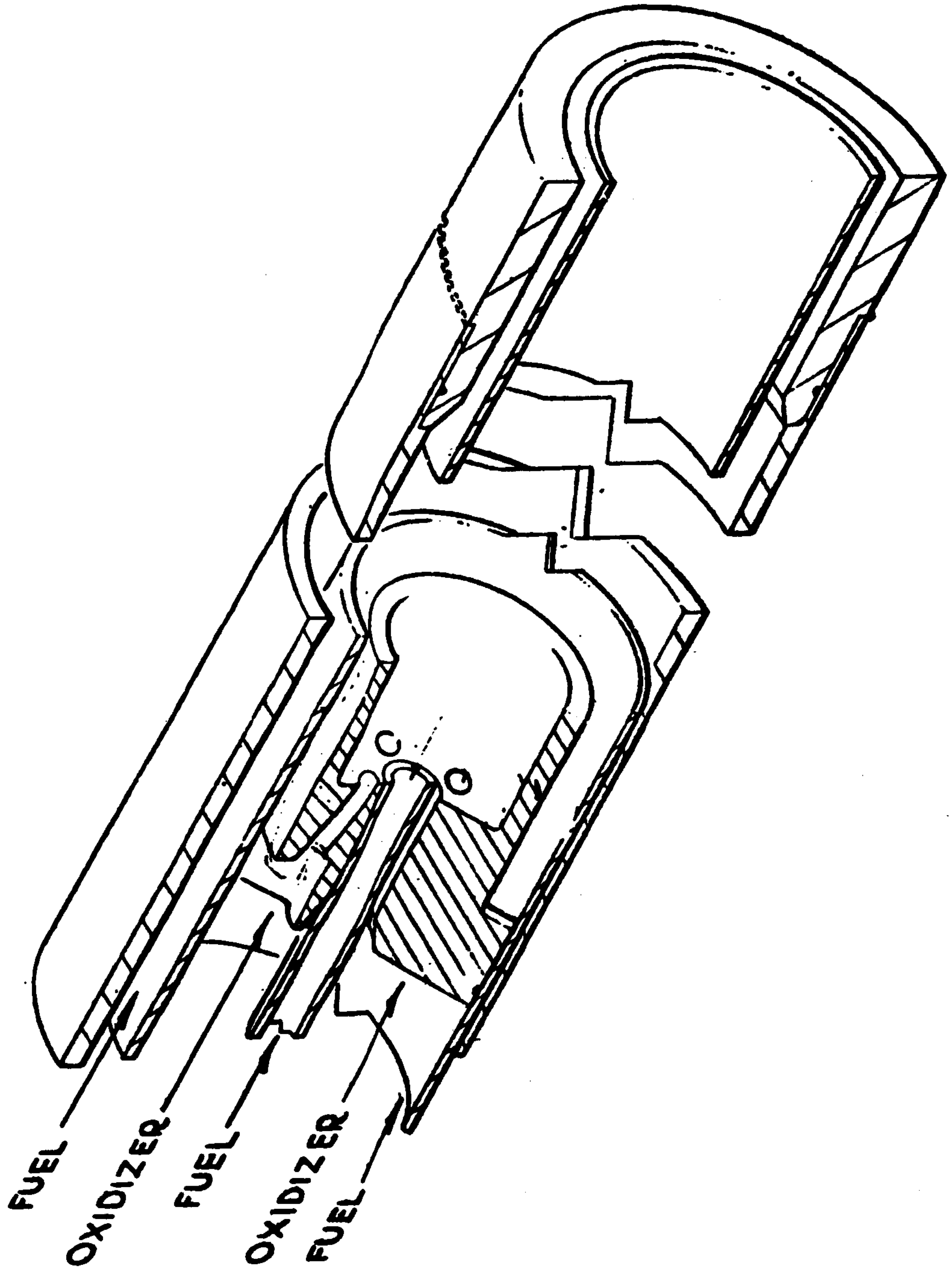

Figure 45. Two-Phase Spud Injector Element No. 1

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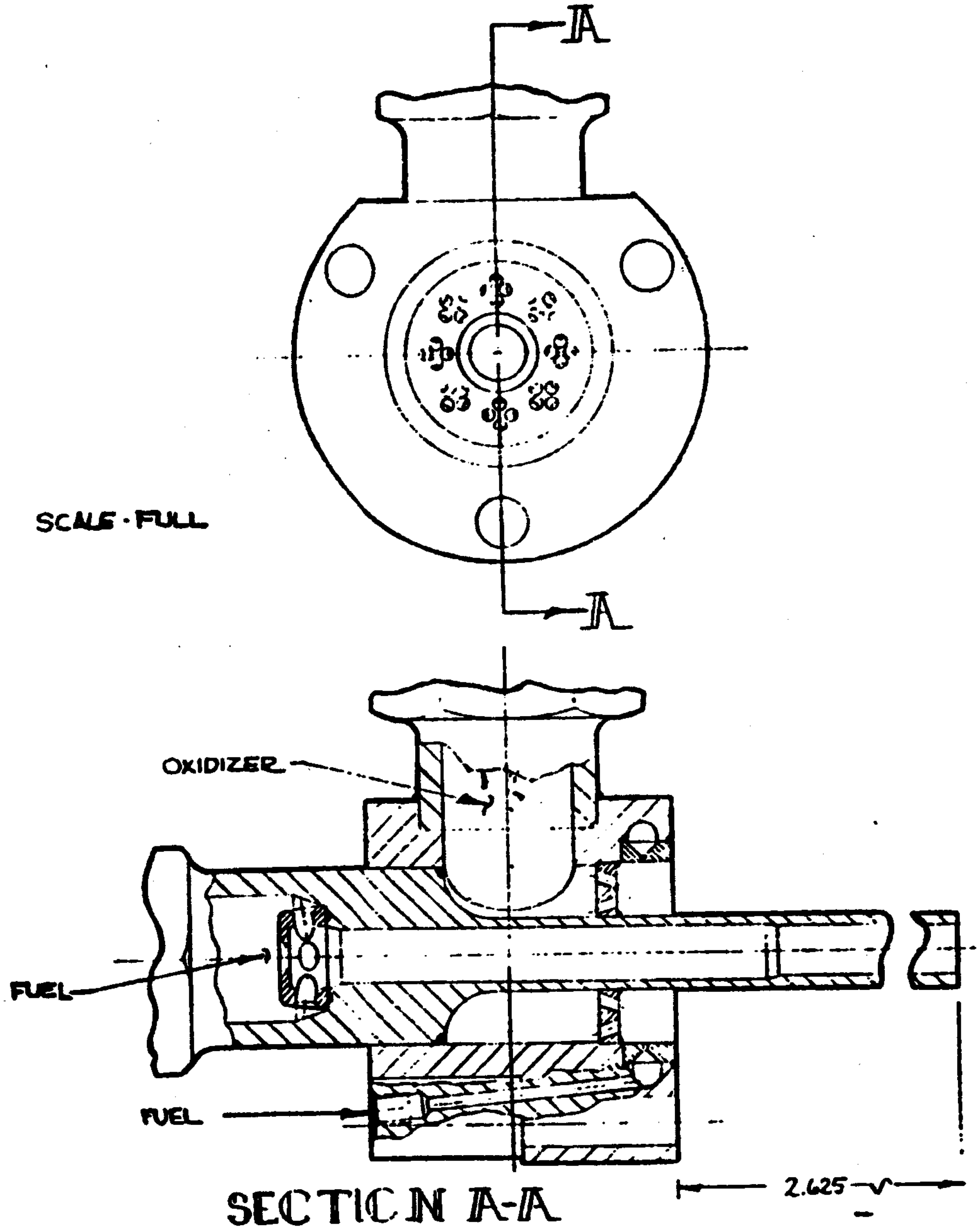

Figure 46. Two-Phase Spud Injector Element No. 2

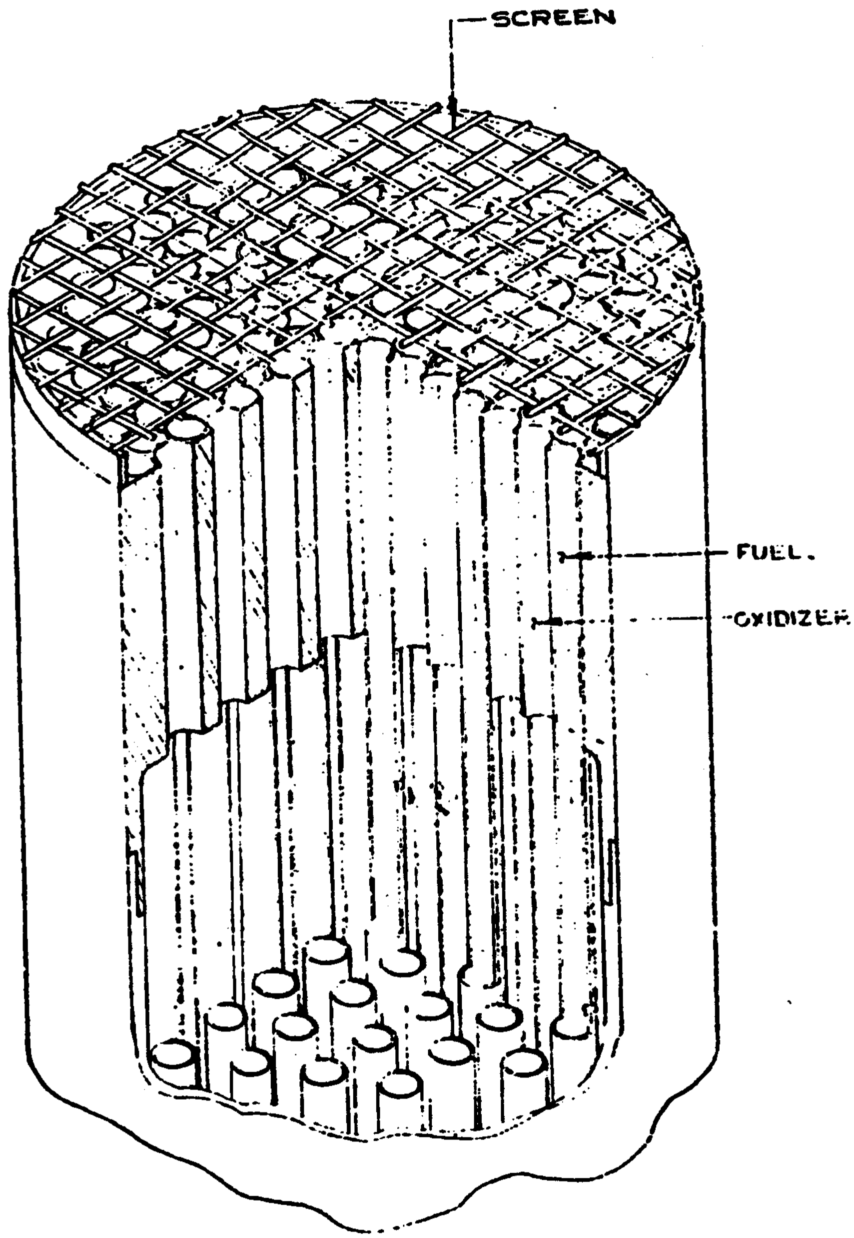

Figure 47. F-1 Spud Injector Element, Multitube

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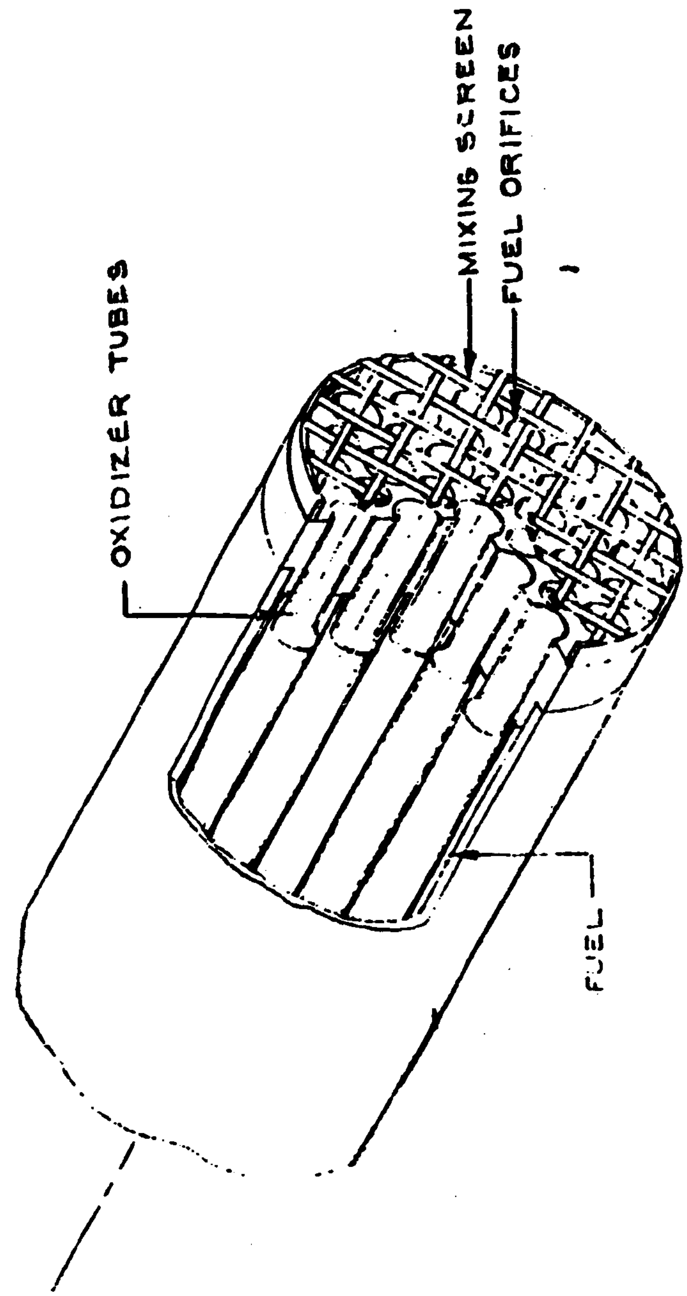

Figure 48. F-1 Spud Injector Element, Screen Spud No. 2

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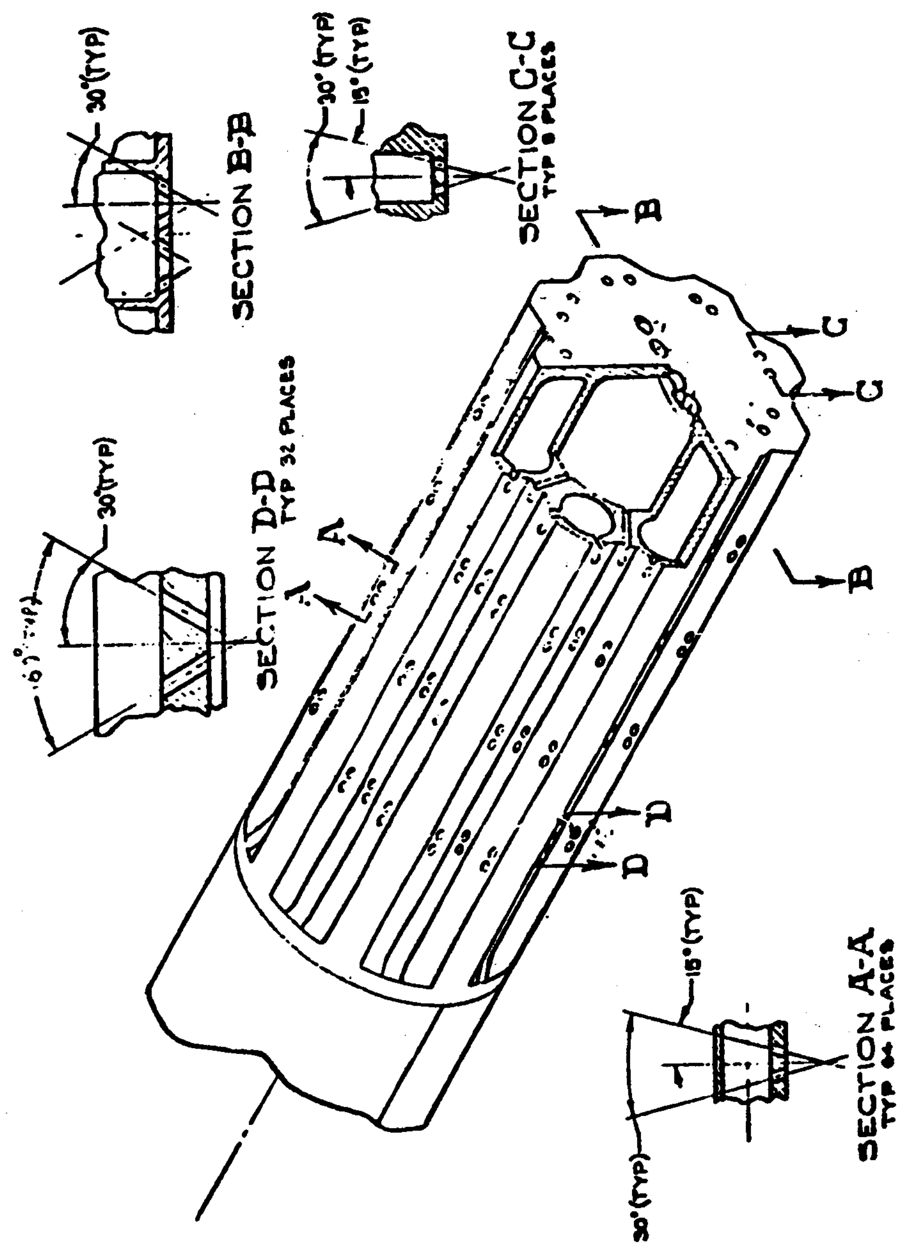

Figure 49. F-1 Spud Injector Element, Radial Flow Spud

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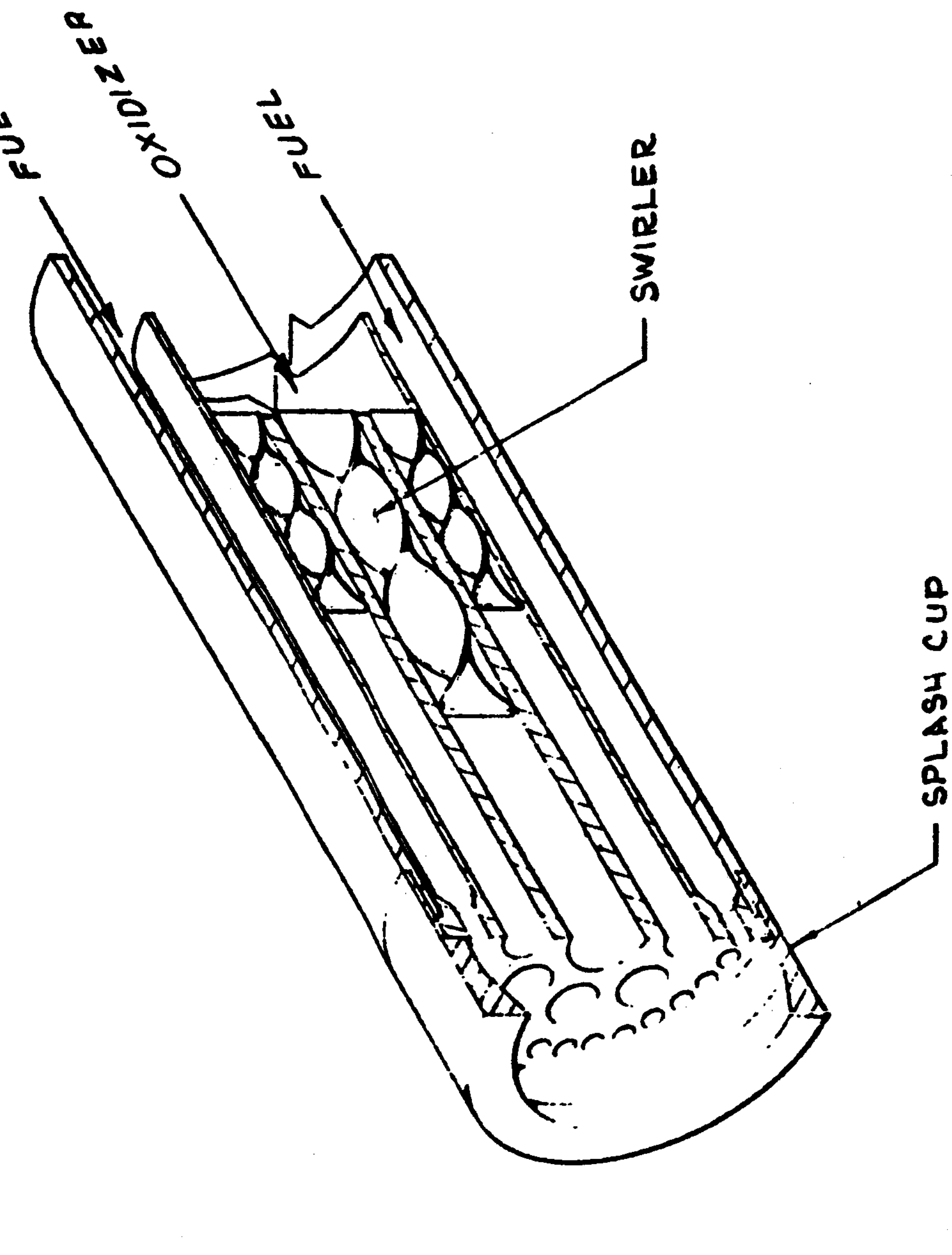

Figure 50. F-1 Spud Injector Element, Cup Spud

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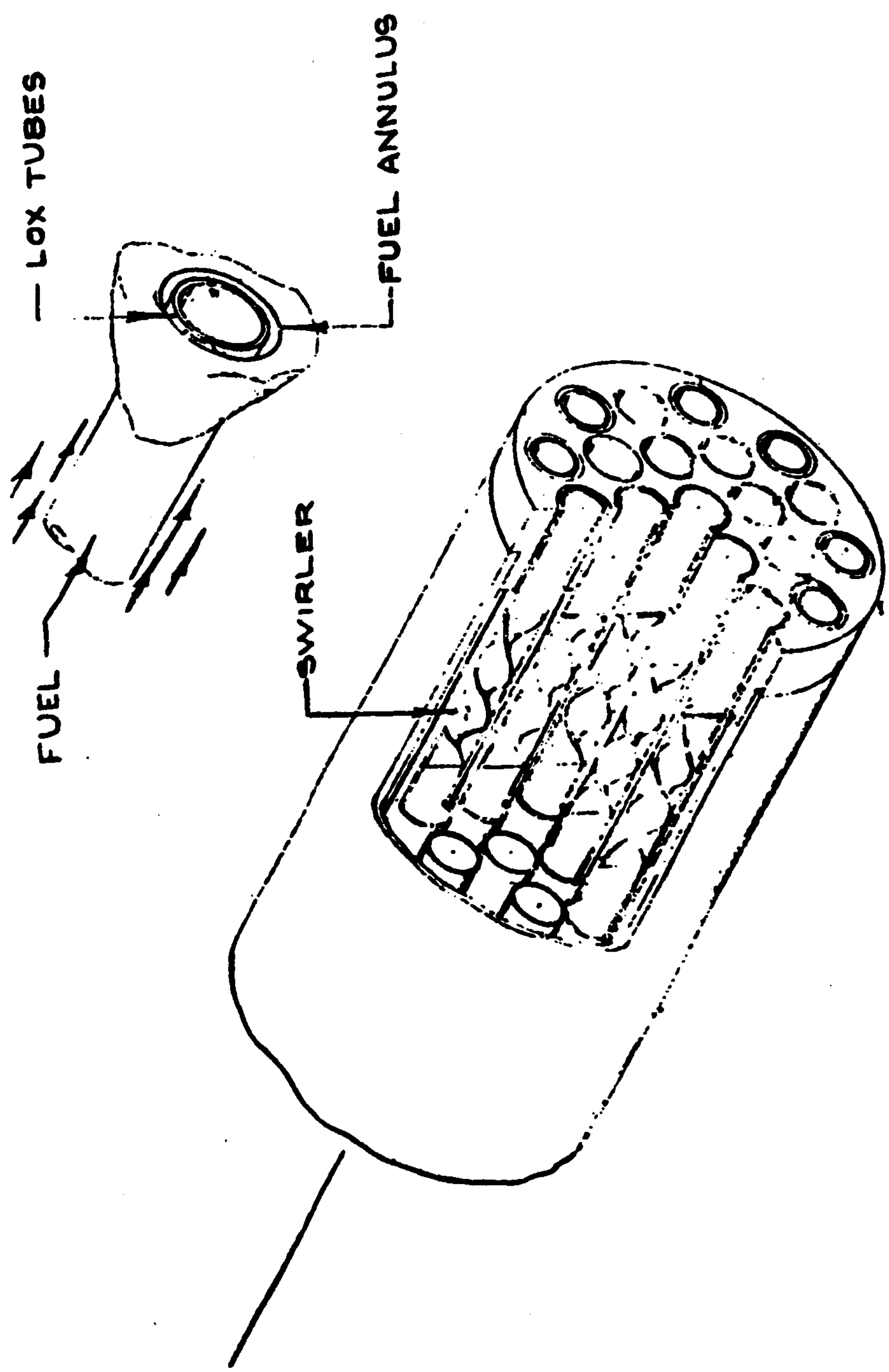

Figure 51. F-1 Spud Injector Element, Concentric Orifice Spud

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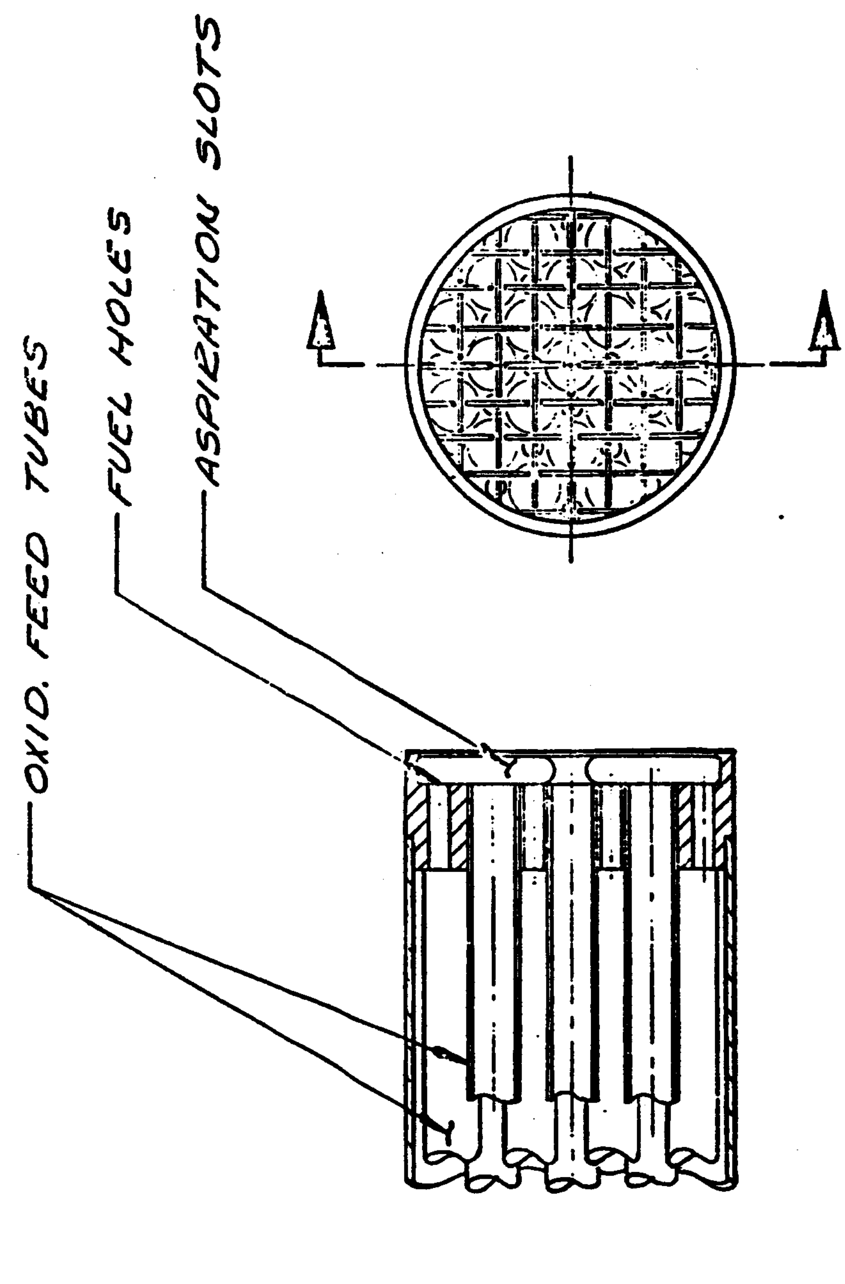

Figure 52. Dual Screen Type Spud

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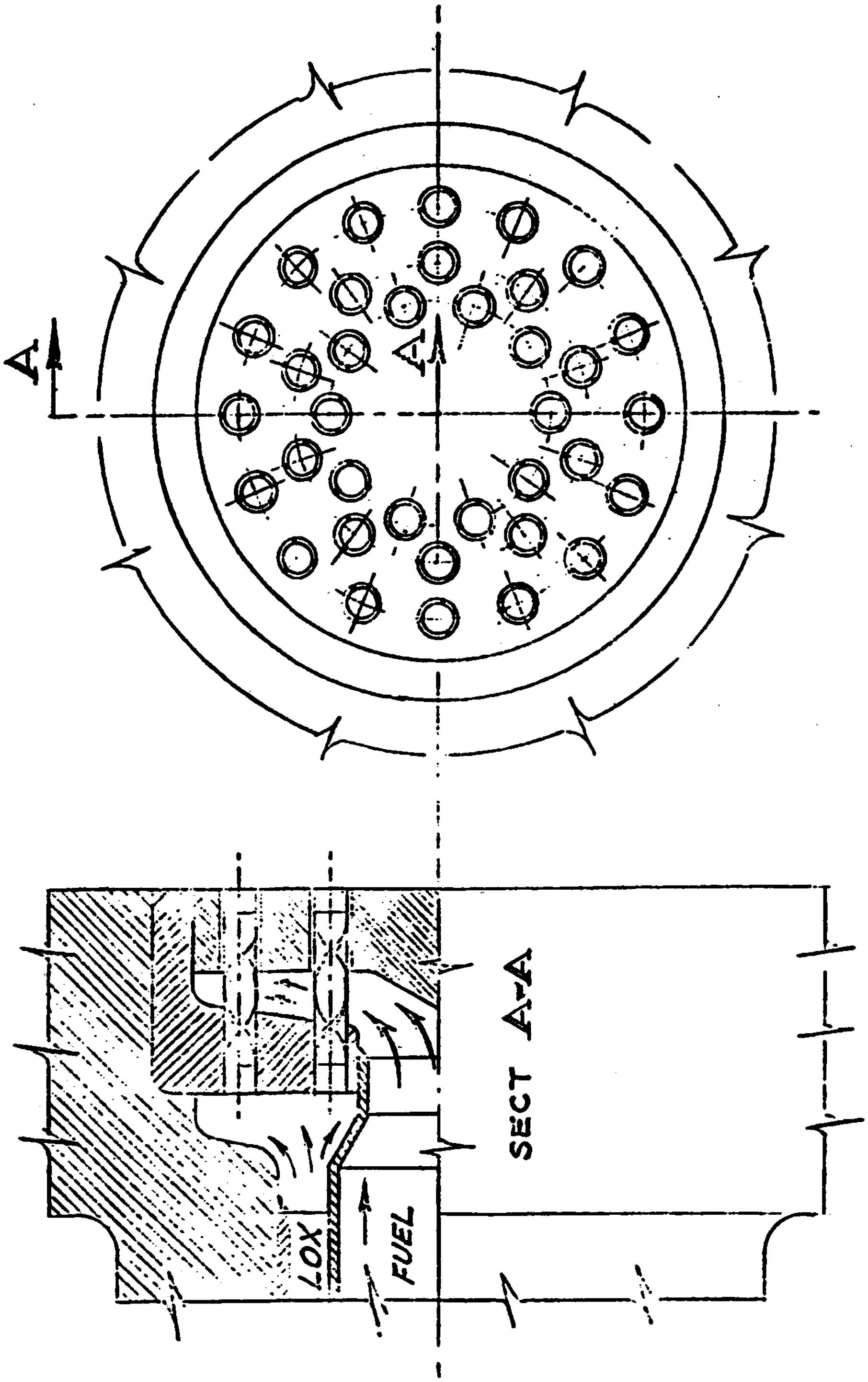

Figure 53. Large Face Concentric Orifice Spud

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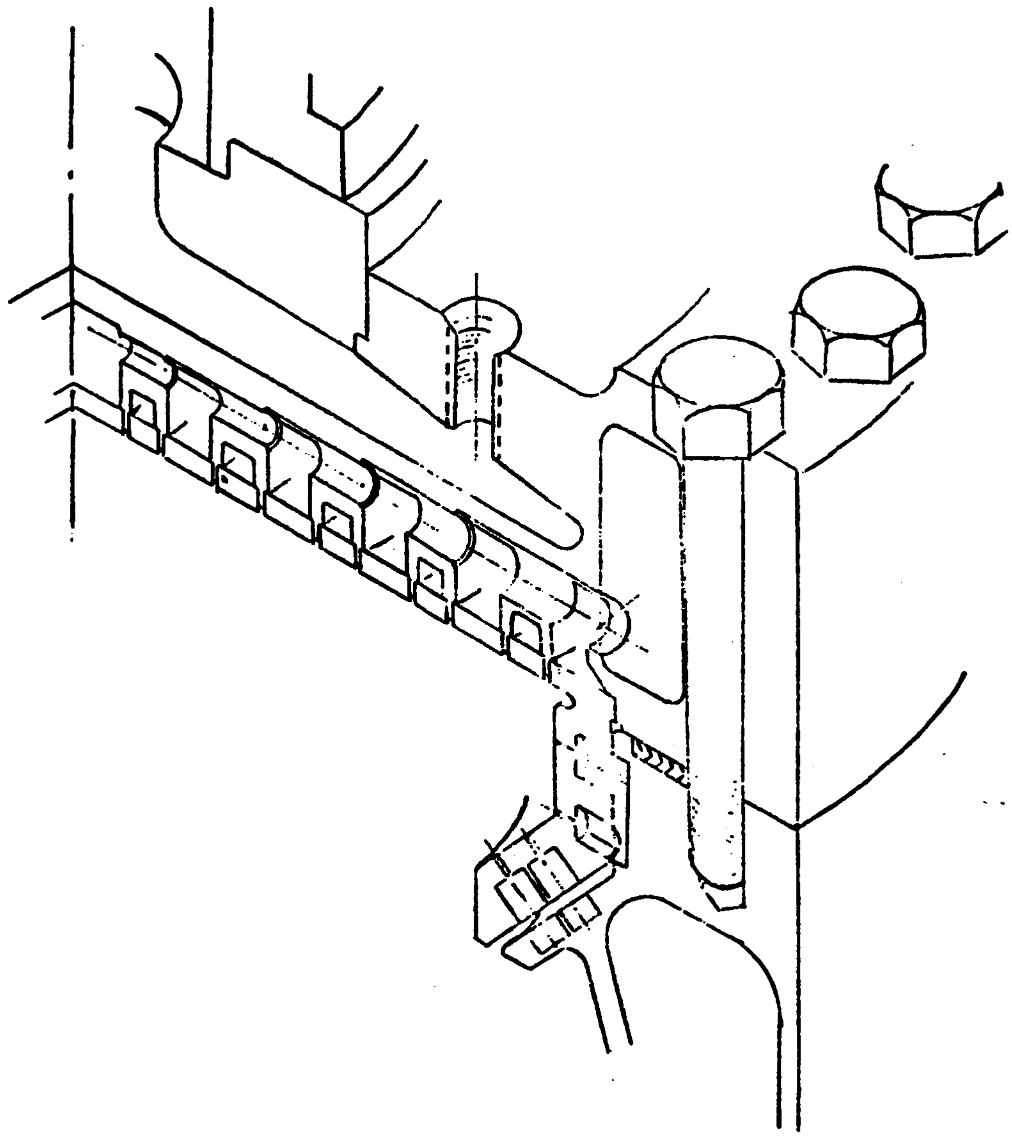

Figure 54. Acoustic Liner for Gas Generator

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The Helmholtz resonators were tuned to 1990 cps, the calculated first tangential mode frequency within the combustor body. Because design calculations were based on incident and reflected plane waves, the expected performance of the liner in a cylindrical cavity was questionable. Therefore, it was decided to build a model acoustic liner and test it in ambient air.

Two models were built. Each consisted of a cylindrical cavity 4 inches in diameter, and having the same first tangential frequency, 1990 cps, as the gas generator. One model had its inner circumference covered with an array of orifices, which was similar to the gas generator design. Fractional open area was identical. The other model had a solid inner circumference. The two models were furnished with top plates containing two holes. These were used to attach a sound generator and microphone 180 degrees apart and reading at the inner wall of the cavity. The test to be conducted on these models was to vary the frequency of the sound generator from 0 to 2800 cps and determine whether the model with the orifices was able to suppress the amplitude of the 1990 cycle frequency. The models were ready to be tested by the end of this period. Also, the fabrication of the gas generator acoustic liner was well under way with testing planned in the month of October.

A full-scale acoustic liner, suitable for use with the F-1 thrust chamber, was also designed. This was to be a cylinder 5 inches long, which would be brazed to the face of the injector, and would contain tubes brazed in radially drilled holes. It was designed for maximum absorption at 710 cps, the tangential frequency of the F-1 thrust chamber with the attached acoustic liner.

BOMB DEVELOPMENT PROGRAM

From April through June, bomb performance continued to be satisfactory with 41 model 4 bombs and 22 model 14 bombs being used to initiate combustion disturbances. All model 14 bombs functioned; one model 4 bomb did not detonate during a two-bomb test. Figure 55 illustrates the two different model bombs. The model 14 bomb has a thinner casing than the model 4 bomb, and is therefore detonated with a shorter time exposure to thrust chamber firing.

Two long-duration bombs were tested during this period. These bombs used fuel cooling and an ablative shield of helically wrapped quartz fibers. One bomb was exposed to 8.4 seconds of mainstage without an explosive charge to check ablative performance. The bomb was recovered intact. The second bomb, with a 13.5-grain charge, accumulated 13 seconds of mainstage time prior to detonation. Also, the bomb withstood combustion disturbances induced by a model 4 bomb during the test.

At this time, it was thought that control of bomb detonation would be desirable. Therefore, an effort was made to improve an electrically initiated bomb. One injector was modified to have an electrical wiring passage leading to a bomb mounted on the injector face. In two tests the bomb was ejected before detonation because of faulty threads in the injector. However, the effort was continued in order to produce a reliable electrical bomb.

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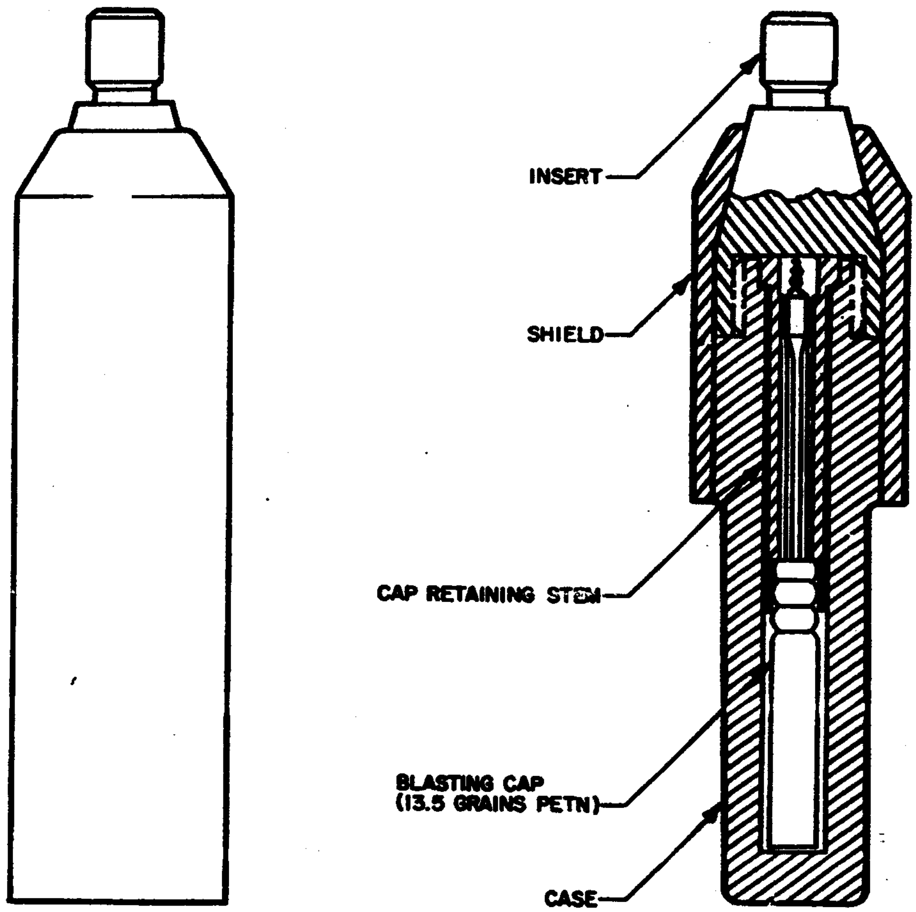

THRUST CHAMBER FIRING DURATION PRIOR TO BOMB DETONATION = 1.1 SECOND

THRUST CHAMBER FIRING DURATION PRIOR TO BOMB DETONATION = 0.7 SECOND

MODEL 4
(INTERIOR DETAIL SAME AS MODEL 14)

MODEL 14

Figure 55. Combustion Stability Bombs, Thermally Detonated

[redacted]

FEED SYSTEM PULSING PROGRAM

Early in 1964 a 500-cycle buzz problem was noted with certain F-1 injector designs. An intensified effort was made to discover the source of feed system resonance with the combustion process. When analytical methods failed to detect the source of the problem, an effort was made to determine experimentally the natural resonant frequency of the chamber-fuel feed system.

All of the fuel orifices in a flat-face injector were brazed shut, and the injector was installed in a solid-wall chamber. The fuel system was filled with water and pressurized. A high-pressure pulse was then introduced into one of the fuel inlets through an explosive pulsing unit. Photocon transducers were used to record the pressure fluctuations within the chamber.

The predominant frequency encountered within the system was between 5000 and 6000 cps. This frequency is similar to one observed in F-1 firings. No 500-cps resonance was apparent in the fuel feed system.

During the testing injector leakage developed and further tests were postponed for repairs. At the time of test suspension, it was discovered that the fuel injection pressure taps in the manifold were not flush mounted and were not of the configuration of tube wall chambers. The possibility of tap cavity resonance became a prime suspect as the 6000 cps mode. It was decided to rework the chamber taps to the tube-wall configuration while the injector was being repaired.

To excite a mode similar to that which is observed in F-1 firings, it was thought that it would be necessary to pulse the system between the fuel inlets. By the end of this period modification of the fuel manifold to add the new pulser location was well under way.

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RESEARCH

During this report period, the research test effort consisted of 16 F-1 two-dimensional, high-pressure firings and two single-spud firings.

TWO-DIMENSIONAL TESTING

The basic goals of the two-dimensional test program were to study buzzing, the effects of resurging, baffle configuration on stability, and temperature distribution in a two-dimensional system.

To study the buzz problem, an orifice pattern identical to injector unit 082 was chosen. Injector unit 082 had experienced buzzing on the full-scale F-1 component tests. The two-dimensional injector utilized 0.281-inch-diameter fuel doublets at 30 degrees and 0.209-inch-diameter oxidizer doublets at 56 degrees 24 minutes.

Table 5 summarizes the tests conducted with the two-dimensional 082 type injector. The conclusions from this test series were:

1. Baffles have distinct effects on stability. The number of baffles and spacing are important.
2. Both propellants in the liquid phase disappear within 1/2 inch of the injector face. However, periodic puffs of liquid fuel were observed.

A two-dimensional injector similar to injector unit X040 was tested with various baffle configurations. Figure 56 illustrates the baffle configurations, and summarizes the testing. Test 2090 experienced a high-amplitude transverse mode, and test 2094 experienced buzzing. The

[redacted]

TWO-DIMENSI

Test No.	Baffle Parameters			Walls	Fuel	P_c ps
	Number	Length, inches	Spacing, inches			
2087	2	3	6.8, 5.8, 6.8	Hybrid	Ethyl Alcohol	10
2089	2	3	6.8, 5.8, 6.8	Solid	RP-1	12
2092	None			Solid	RP-1	10
2093	1	3	9.5, 10	Solid	RP-1	11
2098	2	3	4.5, 9.5, 4.5	Solid	RP-1	11

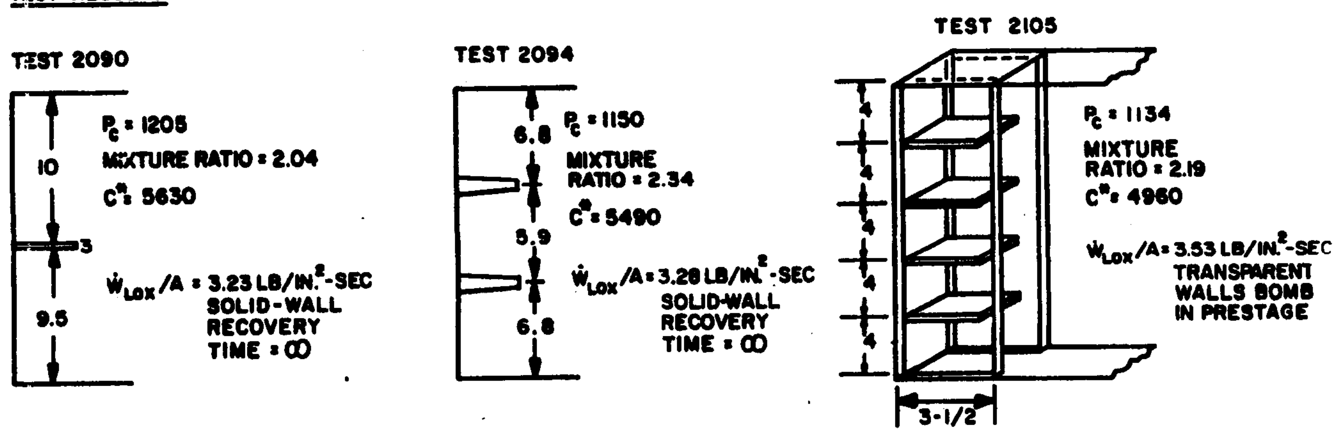
**Recovery time in milliseconds from detonation of 13.5-grain bo

:TOR, TEST SUMMARY

	RT**	Comments
)0	8	In-phase 600-cps noise throughout longitudinal; small amplitude; oscillations near injector obvious in motion pictures
70	75	600-cps noise; baffles lodged 10 inches downstream giving "blobby baffle effects"
-	0	LIMA checkout, spontaneous 900-cps first transverse, steep-fronted 1200 peak-to-peak waves
70	5, 5	RCC; popped 1650-cps second transverse, almost sinusoidal waves; after 180 milliseconds amplitude decayed to stable combustion for 60 milliseconds before P_c decay
-	5, 5	Classical damp; fuel system took 10 to 15 milliseconds to completely damp; no buzz

·om injector face.

[redacted]



Injector pattern used: 0.281-inch-diameter fuel doublets at 30-degrees included angle, 0.238 LOX doublets

Test Number	Baffles		P_c	$\dot{w}_t$	Mixture Ratio	C*
	Number	Length, inches				
2090	1	3	1205	146.4	2.04	5630
2091	1	3	--	--	--	--
2094	2	3	1150	142.6	2.34	5490

NOTES:

No. 2090 Shock triggered second transverse, high-amplitude, sharp-fronted instability which persited until P_c decay. No significant noise prior to bomb.

No. 2094 Prior to bomb, 1000-cps, 100 psi buzz. Bomb triggered high-amplitude, sharp-fronted 2600-cps baffle cavity mode.

Figure 56. Tests Using X040 Type Injector

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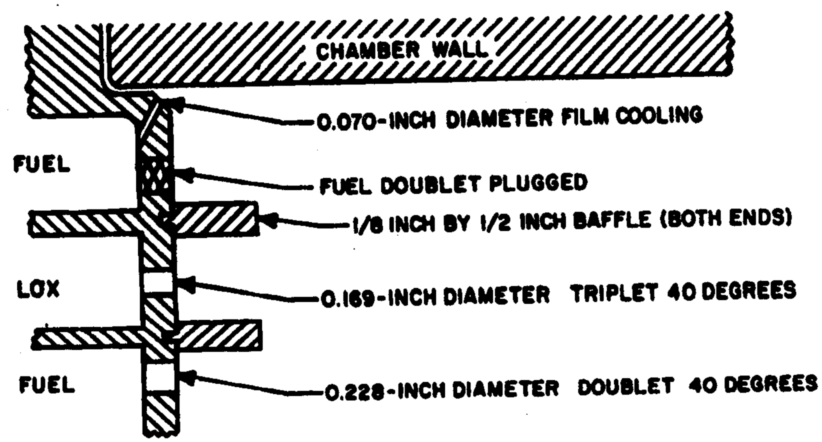
conclusions from these tests again indicated the effect of baffle configuration on mode establishment.

To study the problem of resurging, a two-dimensional injector similar to injector X007 was built. It had been postulated that repeated pressure surging or popping in the F-1 chamber was caused by bits of LOX migrating to the chamber wall and mixing with film coolant fuel, forming a gel. Thus, the two-dimensional, X007 type injector was modified by blocking the fuel doublet next to the wall, and inserting a short, 1/2-inch baffle to allow a "pocket" for liquid mixing to occur without disturbance by the combustion gases. The detail of the injector and the test summary are shown in Fig. 57.

The conclusions from this test series were that the pocket adjacent to the wall did not induce popping or resurging. However, it appeared, although not perfectly repeatable, that oxidizer on the walls of the two-dimensional chamber did increase the damp time over that experienced when fuel was on the walls. The most obvious effect was the increased performance.

During this period, the "blobby" baffles were evaluated in tests 2085 and 2086 but with the divergent half of the outer baffles removed (Fig. 58). The results were similar to previous tests. The performance was high, but there was an appearance of buzz.

Two-dimensional chamber temperature measurements were made during this period. Temperatures just downstream of the injector face were measured using chromel-alumel thermocouples. The following results were observed.



Test Number	Baffle Parameters: Number	Baffle Parameters: Length, inches	Baffle Parameters: Spacing, inches	P_c	Mixture Ratio	c*	RT[x]
**	2	3	6.8, 5.8, 6.8	1100	2.40	4900	5, 15
2095	2	3, 2 1/2	6.8, 5.8, 6.8	1170	2.31	5300	30, 120
2096	2	3, 2 1/2	6.8, 5.8, 6.8	1130	2.00	5370	no bomb
2099	2	3, 2 1/2	6.8, 5.8, 6.8	1106	2.80	5290	10

[x]Recovery time in milliseconds from a 13.5-grain charge at 9.7 inches from injector face.

**Composite of four earlier tests with outer fuel holes open and no 1/2 inch baffles.

Figure 57. Two-Dimensional, X007 Type Injector, Modified

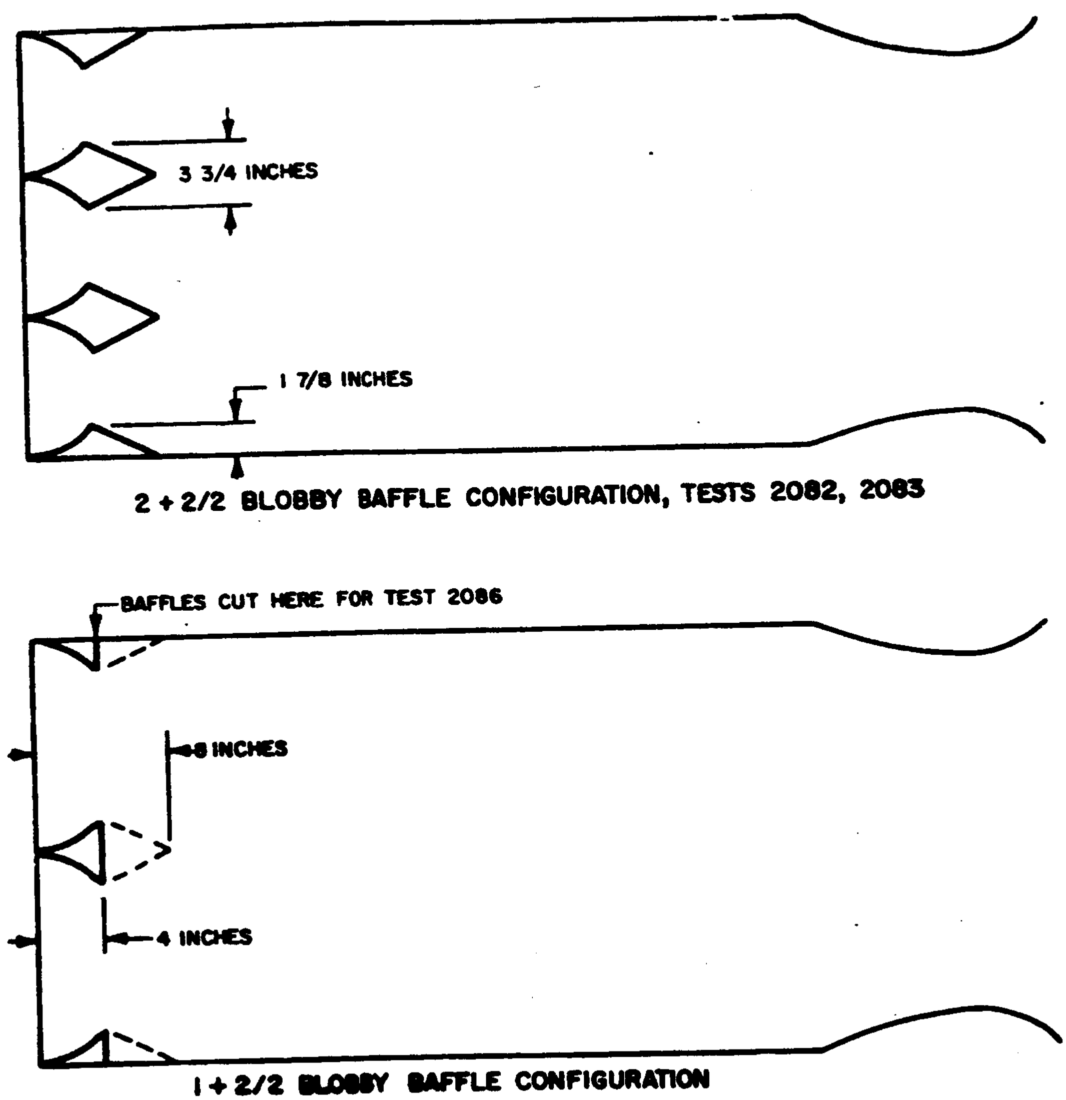


Figure 58. Blobby Baffles

Test 2097

For this test, five 1-inch-long, 10-mil sheathed thermocouples were installed in the 092-type injector. Two thermocouples were centered between LOX and fuel doublets, while two others were centered inside the LOX and fuel doublets, respectively. The fifth thermocouple was placed near the wall just opposite the thermocouple installed in the fuel doublet. Spontaneous instability occurred after 60 milliseconds of mainstage operation.

All thermocouples except the wall thermocouple recorded low temperatures, typifying liquid oxygen and RP-1 injection temperatures. The wall thermocouples recorded a gas temperature of 2400 F. At the onset of instability the temperature at the wall fell to half of its previous value, while other thermocouples recorded temperatures from 1200 to 1700 F, with the exception of the LOX doublet thermocouple, which still recorded the LOX temperature.

It was believed that these measurements gave strong evidence of the winds and recirculation currents which prevail in the baffle cavities during instability.

Test 2098

The seven thermocouples installed in the 082-type injector revealed recirculation currents having higher temperatures than in test 2097. The run was stable throughout. Four thermocouples were destroyed, while three received only slight damage. In contrast, all thermocouples between fuel and oxidizer doublets recorded much higher temperatures than in test 2097.

Test 2100

Test 2100 was a miscellaneous test conducted to investigate flat-face stability and performance. The test is summarized in Table 6 along with the entire two-dimensional testing for this period.

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Test No.	Date	Injector	Chamber	P_c Injector, psig	Mixture Ratio	Puls
2085	4-8-64	081 No. 15, one blobby baffle	Hybrid	$P_c = 1070$ $\dot{w}_t = 107.2 + 44$	2.44	1 gram 9.7 incl from to
2086	4-10-64	081 No. 15, one blobby baffle	Opaque	$P_c = 1123$ $\dot{w}_t = 103.5 + 47$	2.2	1 gram 9.7 inc from to
2087	4-15-64	082B No. 11, two 3-inch baffles at 6.8 and 12.9 inches	Hybrid	$P_c = 1053$ $\dot{w}_t = 108.8 + 46.4$	2.35	Fuel pu 1 gram 9.7 inc from to
2088	4-17-64	X007 No. 9, two 3-inch baffles at 6.8 and 12.9 inches	Hybrid	$P_c = 1070$ $\dot{w}_t = 114.8 + 43.1$	2.63	1 gram at 9.7 from t 9.7 fr bottom
2089	4-22-64	082B No. 11, two 3-inch baffles at 6.8 and 12.9 inches	Opaque	$P_c = 1205$ $\dot{w}_t = 104.5 + 49.6$	2.11	Fuel p 1 gram 9.7 in from t
2090	4-22-64	040 No. 14, one 3-inch baffle at 10 inches	Opaque	$P_c = 1205$ $\dot{w}_t = 98.3 + 48.1$	2.04	Fuel p 1 gram 9.7 in from t
2091	5-1-64	040 No. 14, one 3-inch baffle at 10 inches	Transparent	--	--	Fuel 1 gra 9.7 i from
2092	5-6-64	082B No. 11, no baffles	Opaque	$P_c = 1060$ $\dot{w}_t =$?	?	Fuel 1 gra 9.7 i from
2093	5-12-64	082B No. 11, one 3-inch baffle at 10 inches	Opaque	$P_c = 1130$ $\dot{w}_t = 104.6 + 50.4$	2.08	Fuel 1 gra 9.7 i from

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TESTING

ability	Test Objective	Results
ered liseconds	Same as tests 2082 at 2083 except only one whole baffle was used	Some buzz; good performance
ered liseconds	Same as test 2085, except baffles were cut off at 4 inches, the maximum area point	Good performance
ered liseconds; ered liseconds	Attempt to trigger and observe buzz instability in high-pressure, two-dimensional chamber using alcohol	Motion pictures show pulsating fuel, which apparently increases as alcohol is replaced by RP-1. Buzz was not distinct on pressure records. Pyrex was lost
ered lliseconds; ered lliseconds	Observe effect of hot (220 F) fuel on stability of X007 type injector	Damping obtained, but damp time increased over room temperature RP-1.
ered liseconds; ered lliseconds	Attempt to observe buzz instability with solid walls to limit recirculation	Baffles were lost from the injector face. One lodged 10 inches from injector, another 20 inches from the injector face, giving the effect of blobby baffles on performance
able; RCC	Determine buzz characteristics of this injector	Shear pins on the pulser did not break, but mechanical shock triggered a second transverse mode, which did not damp; first use of high-pressure LOX bleed
—		Late ignition with nitrogen tetroxide and unsymmetrical dimethylhydrazine blew both sides of chamber
taneously able	Observe stability characteristics with flat-face injector; observe triethylboron ignition	Unstable in first transverse mode upon entering mainstage; bad flowmeter readings
taneous; vered 180 iseconds;	Observe stability characteristics with one baffle; observe triethylboron ignition	Spontaneously unstable in second transverse mode; recovered after RCC, but still in mainstage

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Test No.	Date	Injector	Chamber	P_c Injector, psig	Mixture Ratio	Pulse
2094	5-20-64	040 No. 14, two 3-inch baffles at 6.7 and 13.3 inches	Opaque	P_c = 1130 $\dot{w}_t$ = 100.00 + 42.6	2.34	Fuel puls 1 gram at 9.7 inche from top
2095	5-28-64	X007 No. 9, two 3-inch baffles at 6.8 and 12.7 inches	Opaque	P_c = 1170 $\dot{w}_t$ = 103.7 + 45.0	2.31	1 gram at inches fr top and 9 inches fr bottom
2096	6-4-64	X007 No. 9, two 3-inch baffles at 6.8 and 12.7 inches	Opaque	P_c = 1130 $\dot{w}_t$ = 96.2 + 48.0	2.0	1 gram at 9.7 inche from bot and 9.7 inches fr top
2097	6-10-64	092 No. 13, no baffles	Opaque	P_c = 1080 $\dot{w}_t$ = 95.3 + 43.1	2.21	1 gram at inches fr top and 9 inches fr bottom
2098	6-17-64	082B No. 11, two 3-inch baffles at 6.8 and 12.9 inches	Opaque	P_c = 1170 $\dot{w}_t$ = 94.7 + 37.1	2.55	1 gram at 9.7 inch from top 9.7 inch from bot
2099	6-23-64	X007 No. 9, two 3-inch baffles at 6.8 and 12.9 inches	Opaque	P_c = 1100 $\dot{w}_t$ = 105 + 37.1	2.80	1 gram a 9.7 inch from top 9.7 inch from bot
2100	6-29-64	Combs no baffles	Opaque	P_c = 1060 $\dot{w}_t$ = 110.7 + 48.3	2.29	1 gram a 9.7 inch from top 9.7 inch from bot

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:ability	Test Objective	Results
:aneous buzz; ible RCC	Observe buzz characteristics of this injector with wide-base (1.5 inches) baffles	Buzz observed until explosive cap detonation triggered third transverse mode to RCC
rered 30 iseconds; rered 120 iseconds	Observe effect of LOX on wall; outer fuel doublet plugged; 1/2 inch stop baffle 1/8 inch from wall, to investigate resurge	Stable until top bomb triggered third transverse mode for 30 milliseconds; bottom bomb triggered third transverse for 120 milliseconds
le	Reinvestigate unusual damping shown in test 2095	One cap detonated on ignition with no effect; run was stable for full duration
taneously able; RCC	Test flat-face stability and measure chamber temperature near injector	Spontaneous instability occurred after 60-millisecond mainstage operation and was sustained to RCC
vered lliseconds; vered lliseconds	Observe stability characteristics and face temperature profile for this injector	Mainstage duration 585 milliseconds; four themocouples were destroyed and three were intact; very high temperatures were observed
vered :illiseconds	Investigate reproducibility of results obtained in test 2095, with same injector configuration	Only one explosive cap detonated and resulted in 10 milliseconds of instability; combustion was stable for the rest of the 600-millisecond test
able; RCC	Investigate flat-face stability and performance of the Combs injector	Combustion became spontaneously unstable on ignition and sustained until cutoff; injector bowing caused a large leak

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A history of the F-1 Combustion Stability Program from April through June 1964 is presented. Results of studies, tests, and procedures are discussed and graphically presented, and problems encountered are described.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Combustion Stability						
Aceustic Liner						
Hydrodynamics						
Injector						
Two-Dimensional Testing						
F-1 Engine						

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